Universidade de Aveiro Departamento de Biologia
2009

Nuno Miguel Negrões Soares

Co-existência Homem-Fauna na fronteira agrícola da Amazónia

Human-Wildlife Coexistence in the Amazon Agricultural frontier

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Biologia, realizada sob a orientação científica do Prof. Doutor Carlos Manuel Martins Santos Fonseca, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro e co-orientação do Prof. Doutor Eloy Revilla, Investigador Científico do Departamento de Biología de la Conservación, Estación Biológica de Doñana-CSIC(Espanha).

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Dedico esta tese á minha Família por estarem sempre presentes

o júri

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palavras-chave

Amazónia, áreas protegidas, grandes carnivoros, conservação

resumo

Nos últimos anos, a conservação da biodiversidade tem-se revelado como um dos maiores desafios que a humanidade enfrenta, no sentido de salvaguardar o frágil equilíbrio dos ecossistemas no nosso planeta. A procura de medidas de preservação revela-se essencial em zonas de elevada riqueza natural, como são o caso das florestas tropicais da Amazónia, que vêm, sistematicamente, a sofrer um aumento da pressão humana, quer pela expansão da agricultura e pecuária, quer pela crescente exploração dos seus recursos naturais. Neste cenário, as áreas protegidas surgem como um instrumento fundamental para preservação da biodiversidade face à crescente antropização. Aos grandes predadores é reconhecida a importância na manutenção dos ecossistemas pelo *papel-chave* que ocupam nas cadeias tróficas. O impacto a larga escala, consequente da extinção/redução de grandes carnívoros, acaba por afectar aspectos locais (diversidade) ou mesmo regionais (ciclo da água). Por este motivo, o estudo das relações entre os grandes carnívoros e o homem torna-se relevante na definição de políticas de gestão, contribuindo ainda para a avaliação da eficácia de medidas de conservação, como a funcionalidade de áreas protegidas. Com este estudo pretendeu-se avaliar o estado das populações de dois grandes felinos – jaguar (*Panthera onca*) e puma (*Puma concolor*) – numa área protegida (Parque Estadual do Cantão - PEC) e numa área privada (Fazenda Santa Fé - FSF), com o objectivo de aferir a eficácia das reservas naturais, na região do “arco do desmatamento”. As densidades de jaguar e puma foram calculadas ao longo de 3 anos nas estações da chuva e seca. Este estudo contribuiu ainda para um aumento do conhecimento sobre a riqueza de espécies nesta região, nomeadamente dentro do PEC e da FSF. Concluímos que a existência do PEC *per se* não garante a preservação da biodiversidade, uma vez que está fortemente dependente das áreas florestais adjacentes para conservar a riqueza faunística. Simultaneamente, observamos que os grandes carnívoros, quer pelas características biológicas quer pelo conflito directo com o Homem (resultado de predação sobre o gado), podem ser utilizados como *espécies-foco. Observamos ainda que* a monitorização das populações destes carnívoros fornece informação indispensável para a avaliação do impacto das actividades humanas e para definir acções de gestão para esta região. A preservação da biodiversidade no “arco do desmatamento” passa pela implementação de planos de conservação concretos que incidam, nomeadamente, no aumento da fiscalização da lei ambiental e no aumento da sensibilização das populações locais (crescente apoio técnico-educativo), no sentido de fomentar o desenvolvimento sustentável.

keywords Amazon, protected areas, large carnivores, conservation

abstract

Biodiversity preservation emerged in the last couple of years has one of the main worldwide problems and a great challenge for next generation to come, in order to secure quality of live on planet earth. This fact is of particular importance in the Amazon, a region of high biodiversity that suffers an increase human pressure due to expanding agricultural frontier and exploitation of natural resources. In this region protected areas stand as an essential tool to allow coexistence between man and wildlife. Large predators are key elements in ecosystem functioning because of their important role in food chains. The impact of large-scale extinctions/reduction of large carnivores can reach local (diversity of wildlife) and regional (water cycle) effects. Consequently relationship between man and large carnivores is an important issue on management, furthermore helping in the evaluation of conservation measures like protected areas. In this research we focus on determining the status of large cats (jaguar and puma) population inside a protected area (Cantão State Park, CS - Park) and private forest reserve (Santa Fé Ranch, SF - Ranch) in order to evaluate protected area' efficiency in the high human impacted region "arc of deforestation". Using camera-trapping methodology we determine jaguar and puma density in the region throughout three years and different seasons. We also estimate terrestrial vertebrate richness in CS-Park and SF-Ranch. We observed that CS-Park *per se* could not guarantee biodiversity preservation at local level and is strongly depended on the securing neighbouring private forest reserves to maintain fauna diversity. We demonstrate also that large carnivores can be used as focal species in management approach in this area. Due to their specific biological demands and the direct interaction with man (consequence of cattle depredation) monitoring carnivore population status creates knowledge baseline from were we can evaluate human impact and launch specific conservation actions in the region. To achieve ultimate preservation goals we suggest intensification on environmental law enforcement and raise technical and educational support to local population towards a more sustainable development.

"All men by nature desire to know."

Aristoteles

CHAPTER 1
General Introduction and Objectives

1.1- Introduction

Since the emergence of mankind we have based our actions by an anthropogenic perspective of the planet and consider the millions of species that coexist with us as natural resources. From the Human point of view wildlife is a resource and resources are usually managed to provide benefit to people (Conover, 2002). The acknowledgement that biodiversity plays an essential role in human live well-being and ecosystems balance has triggered the urgency of measures that increases the preservation of species and habitats all over the world. In 2002 the Sixth conference of the Parties to the Convention on Biological Diversity (CBD) set as a goal "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth." (CBD, 2000).

The increase of human population and consequent higher need for resources exploration sets a pessimistic scenario for biodiversity in general (McKee et al., 2003). Human-wildlife interactions raise as world population increases exponential and so its demand for land, food and other assets. Consequently many of the world's remaining savannahs, tropical and temperate sanctuaries are under increasing human pressure (Sinclair and Arcese, 1995; Brashares et al., 2001).

The importance attributed to natural resources varies between generations as society changes, together with the consequences of previous exploitation (Conover, 2002). Our incapacity in foreseeing the future and evaluate the impact of our actions should seed engagements that are not irreversible. The high number of species extinct, by direct or indirect intervention of man, is a known, unquestionable and also irrevocable fact (Woodroffe et al., 2005). Research also as revealed that the spatial (local, regional, continental or worldwide) temporal (short or long term, over different human generations) and even ecological (species, community, ecosystem) levels that these extinctions can reach are sometimes beyond predictability (Woodroffe et al., 2005).

1.2- The Amazon, the "Arc of Deforestation" and the Protected Areas

Amazon is the largest tropical rainforest region and faces the fastest level of forest loss in the world (Peres and Zimmerman, 2000; Foley et al., 2007). This increasing pressure is felt mostly in the east and southeastern border, the transition area between the dense Amazon forest and the more sparse *Cerrado* vegetation, called the "Arc of deforestation". Extending over more than 1.6 Million km^2 it stands has the most densely population region in the Amazon basin and has suffered extensive deforestation, in particular for agriculture and cattle grazing (Lopes and Ferrari, 2000). Among other initiatives the Brazilian Government, invested in a basin-wide network of protected areas (from strictly protected areas to indigenous and extractive reserves) in order to slow the advance of deforestation and to effectively preserve the high biological diversity of the region (Peres and Zimmerman, 2000; Azevedo-Ramos et al., 2006). In 2002 the Amazon Region Protected Area Program ARPA was created with the aim "to protect for future generations the full range of biological and ecological features found in the Brazilian Amazon" in foreseen total of 50 000 millions of hectares of conservation units to be established until 2013 (WWF, 2006). Nevertheless, there is still some debate on the efficiency of strictly protected areas for the conservation of biodiversity in remaining tropical forest areas like the Amazon (Peres and Zimmerman, 2000).

1.3- Carnivores and Biodiversity Conservation

Mammals receive a considerable amount of attention within conservation, in a disproportionate rate taking into account that they represent only a small percentage of the total number of species that exists on earth (about 4500 mammalian species of over 1 000 000 taxonomic species classified until 1970) (May, 1990; Eintwistle et al., 2000). Carnivores in particular, are very charismatic and have been used as "flash ship" species in programs for biodiversity and natural habitats conservation.

The preservation of large carnivores in general presents various problems. They usually occur at low densities, present slower life histories, demand large preserved areas and tend to be elusive (making them hard to study) (Karanth and Chellam, 2008; Schipper et al., 2008). Occasionally, they are regarded as conflict species presenting a menace to human and/or their belongings (Inskip and Zimmerman, 2008). Many carnivore species are among the most threatened terrestrial mammals mainly due to habitat loss and fragmentation but also by direct hunting and prey depletion (Ceballos et al., 2005; Schipper et al., 2008). This scenario of conflicts with human activities can restrict large carnivores to natural reserves and adjacent areas in much of the world (Woodroffe and Ginsberg, 1998). In order to insure success in carnivore conservation such reserves must be ecologically intact and their management has to engage a metapopulation approach that goes beyond reserve borders to avoid problems like inbreeding and stochastic phenomenon (e.g. disease outbreak) (Fernández et al., 2007).

Although their importance for ecosystem is recognized, the majority of the carnivore species natural history, particularly in the tropics, remains poorly known (Schaller, 1996; Karanth and Chellam, 2008). The effect of large carnivores in ecosystems features and processes is still not widely understood but some researches already illustrate the importance of the top-down regulation in food webs and how it influences structuring biotic and abiotic systems (Steneck, 2005). A study with puma (*Puma concolor*) in Zion National Park, done by Ripple and Beschta (2006) found that the decrease of this large felid density led subsequently to higher browsing intensity on riparian trees caused by herbivorous (pumas' prey) species, resulting in an increase of bank erosion and reduction in both terrestrial and aquatic species abundance. This study stands has an example of an integrative research at the ecosystem level and should stimulate further similar approaches in different biomes in order to fully comprehend carnivores role on ecosystem function and its representativeness as "key species". This can only be attained with long-term researches based on strictly monitoring protocols of species and environment (Yoccoz et al., 2001).

1.4- Monitoring Carnivores

The biological characteristics of many carnivore species (cryptic, present low population size and nocturnal behaviour) are reflected on the difficulties of collecting information on their natural life history, particularly in determine population size (Wang and MacDonald, 2009). On the other hand, accurate and reliable methods are essential to estimate and monitor populations, assess species richness and evaluate conservation priorities (Silveira et al., 2003). Taking into account the financial and time restrains that limit field researches, there is a need for trade-off evaluation between cost and efficiency of methods used in order to produce quick and precise results.

The most common techniques in carnivore monitoring involves tracking animals using indirect signs like scats and footprints but their environmental pre-requisites and statistical bases restrict them to specific conditions, make them less cost-effective and sometimes fail to produce absolute density estimates (Karanth et al., 2003; Silveira et al., 2003).

In recent years the use of remote triggered photographic camera units for studying carnivores has been popularized, and supported by a capture-recapture analysis statistical framework it has been successfully used in determine density of tiger *Panthera tigris* (Karanth and Nicholds, 1998), puma *Puma concolor* (Kelly et al., 2008), ocelot *Leopardus* *pardalis* (DiBieletti et al., 2006) and including the jaguar *Panthera onca* (Silver et al., 2004). It has also been applied in inventory of mammals (Tobler et al., 2008), habitat selection (Goulart et al., 2009) and comparing mammal and bird diversity inside and outside protected areas (Stein et al., 2008).

1.5- Jaguar and Puma in the Neotropics

The jaguar (*Panthera onca*) and the puma (*Puma concolor*) are the only two large cat species inhabiting the neotropics. There is a deep basic knowledge on pumas' ecology in North America but almost no information concerning the species on Central and South America (Chapter 4 of this thesis). The jaguar has been studied recently in different parts of its distribution range but lacks information on ecology in the largest region that covers the majority of its range: the Amazon basin (Chapter 2 and 3 of this thesis).

Both the jaguar and the puma are considered conflict species due to cattle depredation and either are threatened by habitat loss, prey depletion and direct persecution, exemplifying the current threats challenging all large tropical carnivores (Harmsen, 2006; Palmeira et al., 2008). As top predators these large cats emerge as excellent "umbrella species", since by securing their conservation we ensure the conservation of many of the species that positioned themselves lower down in the trophic pyramid (Carroll et al., 2001).

In resume, large carnivore focal approach can contribute to further understand the human impact on tropical forest ecosystems and establish conservation programmes at a broad scale level using not only the important ecological role of the species but also the charisma they hold among general public.

1.6- Thesis Objectives

The main objective of this dissertation was to comprehend the conservation issues that surround protected and unprotected areas in the Amazon agricultural frontier using large felids' ecology as models.

The increasing anthropogenic pressure in the "arc of deforestation" is indisputable as well as the importance of protected areas for preserving biodiversity and other ecosystems services in the long-term. However the efficiency of protected areas for conservation within present scenario is still an open question that can only be answered at local level with field-collected data. There is a huge lack of information concerning mammals' diversity in this area. There is also a gap of knowledge concerning jaguar (*Panthera onca*) and puma (*Puma concolor*) density for the Brazilian Amazon that we intend to answer using camera trapping approach and capture-recapture analysis.

Using mammals as focal group and large carnivores in specific, we intend to compare the current situation inside a protected area with the one occurring in a private cattle ranch farm contributing with the ecological essential base data: population density.

Setting the status of large carnivore species, understanding the variables that can influence their occurrence within the area and establishing a protocol for long-term monitoring is crucial to evaluate protected area efficiency and human impact on tropical forest ecosystem.

References

Azevedo-Ramos, C. Do Amaral, B.D., Nepstad, D.C., Soares Filho, B. and Nasi, R. (2006). Integrating Ecosystem Management, Protected Areas, and Mammal Conservation in the Brazilian Amazon. Ecology and Society 11(2): 17 [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art17/ Access in 15/5/2007.

Brashares, J.S., Arcese, P. and Sam, M.K. (2001). Human demography and reserves size predict wildlife extinction in West Africa. Procedures of Royal Society London B 268, 2473-2478.

CBD 2000 Decision VI/26. UNEP/CBD/COP/6/20

Carroll, C., Noss, R.F. and Paquet, P.C. (2001). Carnivores as Focal Species for Conservation Planning in the Rocky Mountain region. Ecological Applications 11(4), 961-980.

Ceballos, G., Erlich, L., Soberon, J., Salazar, I. and Fay, J.P. (2005). Global mammal conservation: what must we manage? Science 309, 603-607.

Chape, S., Blyth, S., Fish, L., Fox, P. and Spalding, M. (2003). 2003 United Nations List of Protected Areas. IUCN, Gland, Switzerland and Cambridge, UK and UNEP-WCMC, Cambridge, UK.

Conover M. 2002. Resolving Human-Wildlife Conflicts: the science of wildlife damage management. CRC Press, Boca Raton, Florida. 418 pp.

DiBitetti, M.S, Paviolo, A. and DeAngelo, C. (2006). Density, habitat use and activity patterns of ocelots (*Leopardus pardalis*) in the Atlantic forest of Misiones, Argentina. Journal of Zoology, London 270, 153–163.

Eintwistle A.C., Mickleburgh, S. and Dunstone, N. (2000). Mammals conservation: current contexts and opportunities. In: Eintwistle, A.C. and Dunstone, N. (Eds.) Priorities for the Conservation of Mammalian Diversity: Has the Panda had its day? CUP, pp 1-7.

Fernández, N., Delibes, M. and Palomares, F. (2007). Habitat-related heterogeneity in breeding in a metapopulation of the Iberian lynx. Ecography 30, 431-439.

Foley, J.A., Asner, G.P., Costa, M.H., Coe, M.T., DeFries, R., Gibbs, H.K., Howard, E.A., Olson, S., Patz, J., Ramankutty N. and Snyder, P. (2007). Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. Frontiers in Ecology and the Environment 5(1), 25-32.

Goulart, F.V.B., Cáceres, N.C., Graipel, M.E., Tortato, M.A., Ghizoni, I.R. and Oliverira-Santos, L.G.R. (2009). Habitat selection by large mammals in southern Brazilian Forest. Mammalian Biology, doi:10.1016/j.mambio.2009.02.006

Harmsen, B.J. (2006). The use of camera traps for estimating abundance and studying the ecology of jaguars (*Panthera onca*). PhD Thesis, University of Southampton, 275 pp.

Inskip, C and Zimmerman, A. (2008). Human-felid conflict: a review of patterns and priorities worldwide. Oryx 43(1), 18-34.

Lopes, M.A. and Ferrari, S.F. (2000). Effects of human colonization on the abundance and diversity of mammals in eastern Brazilian Amazonia. Conservation Biology 14(6), 1658-1665.

Karanth, K.U and Nicholds, J.D. (1998). Estimating tiger (*Panthera tigris*) populations form camera-trap data using capture-recaptures. Ecology 79, 2852-2862.

Karanth, K.U., Nicholds, J.D., Seidensticker, J., Dinerstein, E., David Smith, J.L., McDougal, C., Johnsingh, A.J.T., Chundawat, R.S. and Thapar, V. (2003) Science deficiency in conservation practice: the monitoring of tiger populations in India. Animal Conservation 6, 141-146.

Karanth K.U. and Chellam, R. (2008). Carnivore conservation at the crossroads. Oryx 41(1), 1-2.

Kelly, M. J., Noss, A. J., Bitetti, M. S., Maffei, L. and Arispe, R. L. (2008). Estimating puma density from camera trapping across three study sites: Bolivia, Argentina, and Belize. Journal of Mammalogy 89(2), 408–418.

May, R.M. (1990). How Many Species area there? Philosophical Transactions: Biological Sciences 330, 293-304.

McKee, J.K., Sciulli, P.W., Fooce, C.D. and Waite, T.A. (2003). Forecasting global biodiversity threats associated with human population growth. Biological Conservation 115, 161-164.

Nowell, K. and Jackson, P. (1996). Wild Cats: status survey and conservation action plan. Burlington Press, Cambridge, 382 pp.

Palmeia, F.B.L., Crawshaw Jr., P.G., Haddad, C.M., Ferraz, K.M.P.M.B and Verdade, L.M. (2008). Cattle depredation by puma (*Puma concolor*) and jaguar (*Panthera onca*) in central-western Brazil. Biological Conservation 141(1), 118-125.

Peres, C.A. and Zimmerman, B. (2000). Perils in Parks or Parks in Peril? Reconciling Conservation in Amazonian Reserves with and without Use. Conservation Biology 15(3), 793-797.

Ripple, W.J. and Beschta, R.L. (2006). Linking a cougar decline, trophic cascade, and catastrophic regime shift in Zion National Park. Biological Conservation 133, 397-408.

Schaller, G.B. (1996) Introduction: carnivores and conservation biology. In: Gittleman, J.L. (Eds.) *Carnivore Behavior, Ecology, and Evolution*, vol 2. Cornell University Press, Ithaca, NY, pp 1–10.

Schipper, J., Chanson, J.S., Chiozza, F., Cox, N.A., Hoffmann, M., Katariya, V. et al. (2008). The status of the world's land and marine mammals: diversity, threat and knowledge. Science 322, 225-230.

Silveira, L., Jácomo, A. T. A. and Diniz-Filho, J. A. F. (2003). Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114, 351-355.

Silver, S.C., Ostro, L.E., Marsh, L.K., Maffei, L., Noss, A.J., Kelly, M.J., Wallace, R.B., Gómez, H. and Ayala, G. (2004). The use of camera traps for estimating jaguar *Panthera onca* abundance and density using capture/recapture analysis. Oryx 38(2), 148-154.

Sinclair, A.R.E. and Arcese, P. (Eds.) (1996). Serengueti 2: dynamics, management, and conservation of an ecosystem. University of Chicago Press, Chicago, IL

Stein, A.B., Fuller, T.K. and Marker, L.L. (2008). Opportunistic use of camera traps to assess habitat-specific mammal and bird diversity in northcentral Namibia. Biodiversity and Conservation 17, 3579-3587.

Steneck, R.S. (2005). An Ecological Context for the Role of Large Carnivores in Conserving Biodiversity. In: Ray, J.C., Redford, K. H., Steneck, R. S. and Berger, J. (Eds.) Large Carnivores and the Conservation of Biodiversity. Island Press, pp 1-33

Tobler, M.W., Carrillo-Percastegui, S.E., Leite Pitman, R, Mares, R. and Powell, G. (2008). An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. Animal Conservation 11, 169-178.

Wang, S.W. and MacDonald, D.W. (2009). The use of camera traps for estimating tiger and leopard populations in the high altitude mountains of Bhutan. Biological Conservation 142, 606-613.

Woodroffe, R. and Ginsberg, J.R., (1998). Edge Effects and the Extinction of Populations Inside Protected Areas. Science 280, 2126-2128.

Woodroffe, R., Thirgood, S and Rabinowitz, A. (2005). The impact of human-wildlife conflict on natural systems. In: Woodroffe, R., Thirgood, R., S. and Rabinowitz, A. (Eds.) People and Wildlife: Conflict or Coexistence? CUP, pp 1-12.

WWF (2006). The Amazon Region Protected Areas Program (ARPA). Available at www.worldwildlife.org/wildplaces/amazon/projects/arpa.cfm#factsheets

Yoccoz, N.G., Nicholds, J.D. and Boulinier, T. (2001). Monitoring of biological diversity in space and time. Trends in Ecology and Evolution 16, 446-453.

"True human goodness, in all its purity and freedom, can come to the fore only when its recipient has no power. Mankind's true moral test, its fundamental test (which lies deeply buried from view), consists of its attitude towards those who are at its mercy: animals."

The Unbearable Lightness of Being

Milan Kundera

CHAPTER 2

Jaguar presence and abundance in the Amazon agricultural frontier: implications for its conservation

Jaguar presence and abundance in the Amazon agricultural frontier: implications for its conservation

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Abstract

The jaguar (*Panthera onca*) is classified as near threatened due to habitat destruction, prey depletion and direct persecution. The Brazilian Amazon is the largest continuous area within its distribution range but there the status of the species remains unclear. We used camera trapping to estimate jaguar density and evaluate the factors affecting its presence and relative abundance at the Amazon forest-agriculture frontier in a protected state park and the private forest of an adjacent cattle ranch in central Brazil during several seasons of sampling. We obtained a total of 175 pictures of 22 different individuals with a sampling effort of 7929 camera-nights. Jaguar capture rates did not differ between years and seasons, but were lower in the park, where we could not estimate density. In the ranch forest, the average jaguar density was 5.61 individuals/100km^2, higher than densities found in other Brazilian biomes except for the Pantanal. The probability of detecting jaguar presence was higher in roads than in trails (six times higher). Relative density was higher in the private ranch forest and it was strongly associated with the richness of species confirming the importance of jaguar as an umbrella species. In the Amazon, legally required private forest reserves within farms and ranches can help to preserve the jaguar and many other species, always and when they are properly managed and the regional connectivity of the forest is not lost. Further research on mortality patterns and on population trends are needed as baseline for jaguar conservation in the Amazon.

Key words: arc of deforestation, Brazil, camera-trapping, density estimation, individual identification, *Panthera onca*, private forest reserves

2.1- Introduction

The Amazon basin is the largest biodiversity hotspot in the world. Large tracts of prime forest are transformed into agricultural land each year, particularly at its outer margins (Morton et al., 2006). In an attempt to preserve part of this natural heritage, a network of protected reserves is being implemented with variable success and, simultaneously, current legislation enforces the preservation of large tracts of forest inside the new farms created at the agricultural frontier (80% must be protected forest inside each ranch). The effectiveness of these conservation measures in helping to offset the impact of the resulting fragmentation of the forest is unknown. The arc of deforestation is exposed to an increased pressure from human occupation that results in a mosaic landscape of agricultural farms and forest patches of various sizes, being considered the most active land-use frontier in the world in terms of total forest lost and intensity of fire activity (FAO, 2006; Giglio et al., 2006; Morton et al., 2006). Additionally, the remaining forest fragments are threatened by a constant increase in human density and, consequently, exploitation (Soares-Filho et al., 2006). Between the first species to be affected by forest loss and fragmentation are those with the largest spatial requirements, particularly large carnivores.

The jaguar *Panthera onca* (Linnaeus, 1758) is one of the largest cats in the world and, throughout its range, from southern USA to northern Argentina, presents a declining population trend due to habitat destruction, prey depletion and direct persecution (IUCN et al., 2008; Nowell and Jackson 1996; Rabinowitz and Nottingham 1986; Weber and Rabinowitz 1996). The synergistic interaction between these factors caused the distribution range of the jaguar to shrink by more than 50% during the XXth century, resulting in a fragmented range (Sanderson et al., 2002; Swank and Teer, 1989). As a result, the species is currently classified as near threatened according to IUCN et al. (2008) and its level of legal protection has increased in all the countries that it still occupies, except for Guyana and Ecuador. The majority of the distribution range is located in Brazil, mostly concentrated in the Amazon basin (88% of the largest continuous area of jaguar range), with the southern Amazon/Cerrado region situated in the arc of deforestation being the largest area with deficient data (Sanderson et al., 2002). The increased loss of natural forested areas in the Amazon, particularly in the agricultural frontier where large natural forested patches remain imbibed in a matrix of agricultural fields, triggers the necessity of understanding how this is affecting jaguar conservation.

In this paper we examine the conservation status of the jaguar in the arc of deforestation at the southern agricultural frontier of the Amazon basin in central Brazil, particularly by estimating the population size and densities and the variables associated with jaguar presence and relative abundance along different sampling seasons in a protected reserve and the forest remaining in an adjacent agricultural ranch.

2.2- Material and Methods

2.2.1- Study Area

The study was carried out in two sites (a protected area and a farm) located at opposite sides of the Araguaia river (Tocantins State, Brazil): the Cantão State Park (CS-Park) and the Santa Fé Ranch (SF-Ranch, Fig. 2.1).

Figure 2.1 – Study area located in the Amazon transition region with Cerrado.

The Cantão State Park (09º36'S, 50º03'W) is an 89 000 ha protected area situated in the transitional area between the Amazon and the Cerrado biomes. The large network of rivers, channels and lakes shows a typical seasonal flooding with strong variations in water level. The wet season (November-March) is followed by a prolonged dry season (April-October; SPMA, 2000), resulting in an annual average precipitation of 1 710 mm and a difference of more than 4 m in river level (data from Santa Fé Ranch). Flooding patterns influence vegetation structure and the resources available for the fauna (food and shelter) both in space and time.

Vegetation is mainly represented by secondary growth tropical rainforest typical of the Amazon with some small areas being occupied by grasslands. Normally, the park is partially flooded during the wet season. Santa Fé Ranch (09°34'S, 50°21'W) is a 65 000 ha beef cattle ranch in the southeast Pará State. Around 65 % of the ranch is covered by a continuous semi-deciduous seasonal tropical forest that extends beyond the farm boundaries, while the other 35% is almost entirely pastures. The area is located in the arc of deforestation, a transitional area between the Savannah (Cerrado) and Amazon ecosystems, where due to an intensified human occupation increases the forest fragmentation in a matrix of agricultural farms lands (Morton et al., 2006).

2.2.2- Field methods

The research is part of a long-term jaguar density monitoring program, designed to study the population status of the jaguar together with other carnivores and their main prey species. Like all elusive species, jaguars are difficult to detect and monitor (Rabinowitz and Nottingham 1986). Camera trapping has been a successful method used to evaluate the status of several species of wildcats (e.g. tigers *Panthera tigris* Karanth and Nicholds, 1998; 2002; puma *Puma concolor* Kelly et al., 2008; ocelot *Leopardus pardalis* DiBieletti et al., 2006; Dillon and Kelly, 2007), including the jaguar (Maffei et al., 2004; Salom-Pérez et al., 2007; Silver et al., 2004; Silveira et al., 2003; Soisalo and Cavalcanti, 2006). In these cases, the data from photographic sampling is analysed within a capture-recapture statistical framework, in order to estimate population density (Karanth and Nicholds, 1998; Stanley and Burnham, 1999). The technique has the advantage of being cost-effective by providing positive species identification and detecting cryptic animals with inconspicuous habits with low disturbance effect.

We conducted five camera trap surveys (2-month periods, on average 64 days), between July 2005 and November 2007, during both the dry (three samplings) and wet seasons (two samplings). Our total sampling effort was 7 929 trap-nights, with a variable number of trap nights (average 965 trap-nights) at each site-period (Table 2). A variable number of stations (from 10 to 22, average 15 stations) were set throughout the area maintaining a distance between 1 km (to avoid spatial autocorrelation) and 3 km (following a specific protocol to estimate jaguar density, Karanth and Nicholds, 2002; Rabinowitz and Nottigham, 1986; Silver, 2004; Silver et al., 2004). Every station consisted of one passive infrared camera set on dirt roads or trails (animal or human made), at approximately 50-70 cm above the ground, except during the 2007 dry season at SF-Ranch, when we used two cameras per station (Silver, 2004). During the study, we used two types of camera: Camtrakker (Cam Trakker, Watkinsville, USA) and C1-BU (Vibrashine Inc., Taylorsville, MS 3968, USA). Each camera was programmed to work 24h/day with a 5-min interval between photos. All stations were checked on a regular basis (5-20 days) throughout the surveys for maintenance purposes (film and battery).

We used individual photographs to collect information concerning the species, number of individuals, sex (female/male), age (adult/sub-adult/juvenile/cub), date and hour. Each photo was considered as an independent event if meet one of the following criteria: consecutive photographs of different individuals of the same or different species; consecutive photographs of individuals of same species taken more than 1 hour apart; non-consecutive photos of individuals of the same species (O'Brien et al., 2003). For each camera location we calculated a Relative Abundance Index (RAI) for all species by dividing the number of independent captures multiplied by the average group number for the species and divided by effort (trap-nights) times 100 (Kawanishi and Sunquist, 2004; O'Brien et al., 2003; Silveira, 2004). We calculated a relative Biomass Abundance Index (BAI) for each camera location by multiplying RAI by the mean weight reported for each species in the bibliography (IUCN et al., 2008; Sick, 1997).

2.2.3- Data Analyses

Each trap location was characterized according to several numerical and categorical variables: area (CS-Park/SF-Ranch); year; place (road/trail); minimum distance to road, pasture, river and water source (all of them in meters); biomass of prey (based on BAI); richness of species and prey species (total number of species and prey species detected with camera trapping, respectively). We did not use variables associated directly to vegetation due to its relative homogeneity within the two areas (SF-Ranch/CS-Park) at a macro scale level. We considered two dependent variables: jaguar presence/absence and number of jaguar photos at each trap location (jaguar relative abundance). For the later we used the sub-sample of observations were there was at least one jaguar photo. We designed the statistical models after four initial hypotheses (Table 2.1): 1) jaguar presence and relative abundance varied in time, space and sampled area; 2) jaguar mainly requires prey availability with a positive preference towards peccaries (particularly *Pecari tajacu*); 3) human disturbance is the main determinant of jaguar presence and abundance; 4) jaguar is affected by a combination of both anthropogenic and environmental factors (Pierce *et al.*, 2000; Weckel *et al.*, 2006). In case of multicolinearity we selected the variable with a higher correlation with the dependent variable. In all models we controlled for the sampling effort at each camera trap location by including the number of days of camera activity as a variable, while the sampling location was included as a random variable. We compared the different models by using the Akaike Information Criterion (AIC), selecting the model with lowest AIC. For each hypothesis we began by fitting all variables included and then, successively removing the terms which decreased the AIC the most (Crawley, 2002). Trap location code was included as a random variable in all models. Overdispersion was not a problem (DF $\approx$ 1.04) in any of the models. We used the procedure GLIMMIX in SAS (SAS Inst. Inc., Cary, NC) and R v.8.2 free statistical software and the Lme4 package for mixed models (Bates and Sarkar, 2006) to fit the statistical models.

Table 2.1 – Variables used in the models evaluating the different hypotheses on the main factors affecting jaguar presence and abundance.

		Hypotheses		
Variable	**Description**	**Sampling**	**Food**	**Human Disturbance**
Area	SF-Ranch/CS-Park	X		X
Year	2005/2006/2007	X		
Place	Road/Trail	X		
Distance to road	Minimum distance to road (meters)			X
Distance to pasture	Minimum distance to pasture (meters)		X	X
Distance to river	Minimum distance to river (meters)			X
Distance to water	Minimum distance to closest water source (meters)		X	
BAI Index	Biomass of Prey Abundance index of prey species		X	
Richness of Prey species	Number of prey species present		X	
Richness of Species	Total number of species photographed at the station		X	
Peccary presence	Presence/absence of peccary species		X	

2.2.4- Density estimations

We identified individual jaguars using their unique pattern of spots in the skin, allowing us to construct a capture history for each survey and individual using a standard "X-matrix format", in which 1 indicates capture of a particular individual during a specific sampling occasion, and 0 that the animal was not captured during that occasion (Karanth et al., 2004). Each sampling occasion consisted of a collapse of the data acquired in 10 consecutive days of trapping. We obtained abundance estimates using the software CAPTURE (Rexstad and Burnham, 1991) following the procedures described by Otis et al. (1978), White et al. (1982), and Karanth and Nichols (1998). This program tests several models, which differ in their assumed sources of variation in capture probability: the null model M_0 (which assumes no variation between individuals or over time); the heterogeneity model M_h (assuming individual heterogeneity due to age, sex, ranging patterns, etc.); the time variation model M_t (assuming that capture probabilities can change along time) and the behavior model M_b (which results from different responses to capture and recaptures). The software identifies the best-fitting model as a function of data (number of individual animals captured and the frequency of recapture) and generates abundance values. Density estimates were determined by dividing jaguar abundance by the effective trap area (Silver et al., 2004). Since almost all of the samplings had only one camera per station, we built the capture history using data concerning only one side (left or right, depending on the one that presented the highest number of captured-recaptured individuals). To determine the effective trap area we estimated the Mean Maximum Distance Moved (MMDM) using data from all the individuals recaptured (Karanth and Nicholds, 1998). We calculated MMDM independently for each survey using Spatial Analyst tool in ArcView (ESRI 1999). We computed sampled area sampled by buffering each trap station with a width corresponding to half of the MMDM (Karanth and Nicholds, 2002; Kelly et al., 2008; Salom-Pérez et al., 2007; Silver, 2004; Soisalo and Cavalcanti, 2006).

2.3- Results

2.3.1- Capture Success

We photographed a minimum of 22 different individuals during the total surveys and were able to determine the sex of 14 animals (11 males and 3 females, Table 2.2). Two of the photographed jaguars were melanic and other two occurred both at SF-Ranch and

CS-Park camera-stations. In total, we obtained 175 pictures of jaguar, representing a capture success (RAI) of 1.21 captures/100 trap-nights (0.22 for CS-Park and 3.71 for SF-Ranch). On average, we obtained 1.37 (SE = 0.214, range 0 - 13) jaguar photos per trap. The jaguar photographic index was higher at SF-Ranch than at CS-Park in all the sampling campaigns (Table 2.2). There were no statistical differences between the average RAI within seasons and years at CS-Park (*Mann-Whitney U-Test* $P \geq 0.416$) or at SF-Ranch (*Mann-Whitney U-Test*, $P \geq 0.05$), while CS-Park and SF-Ranch RAI´s differed both in 2005 and 2006 campaigns (*Mann-Whitney U-Test* W = 187, $P = 0.005$ and W = 840, $P < 0.001$ respectively). On average, we obtained jaguar photographs in 46.7 % of the trapping stations (range 9.1 - 20% for CS-Park; 42.9 - 82.4% for SF-Ranch). The number of locations with one or more photos of jaguar presents an expected Poisson distribution, with about 60% of the stations having more than one picture.

2.3.2- Jaguar Density

The low number of capture-recaptures made impossible the use of CAPTURE for CS-Park data. The density estimates for SF-Ranch ranged between 3.3 individuals/100 km^2 (for 2007 dry season) and 9.6 individuals/100 km^2 (for 2006 dry season, Table 2.3). We could not reject the closure assumption for any camera survey at SF-Ranch (Table 2.3). Since M_h model had the highest (or second highest relative to the null model) selection value in all the samplings, we chose it to estimate population size for each survey. By assuming heterogeneity among individuals in their capture probabilities, the jackknife population model (M_h) is probably the most biologically plausible, since jaguar territorial behaviour can cause unequal access to sampling stations by different individuals (Dillon and Kelly, 2007; Karanth and Nicholds, 2002; Otis et al, 1978; Silver et al., 2004). An average number of 5 recaptured animals (between 4 - 6) was use to estimate MMDM. The mean maximum distance between recaptures of individuals was 3.3 km (1.6 - 17.6 km) for all the samplings. The effective survey area ranged from 117 km^2 to 215 km^2, being generally higher during dry seasons.

Table 2.2- Results of six camera trapping campaigns carried out in the Cantão State Park and Santa Fé Ranch in Central Brazil. Nº Stations is the number of camera trap stations active throughout the sampling; Total Effort is the total number of days camera stations were functional; Mean Days is the average number of days cameras were active per sampling campaign; Mean RAI is the average number of photos of jaguar/number of days camera was active times 100; Range RAI are the minimum and maximum RAI estimates; %Detections is the % of camera stations that presented at least one jaguar photo.

	Cantão State Park			Santa Fé Ranch				
	2005	2006		2005	2006		2007	
	Dry	Rain	Dry	Dry	Rain	Dry	Rain	Dry
Nº Stations	21	10	22	12	14	17	11	21
Total Effort	1390	626	1167	764	662	1114	525	1681
Mean Days	66	63	53	64	47	66	48	80
C/R/N[1]	3/0/3	2/0/2	1/0/1	16/4/6	17/3/6	23/6/11	18/4/5	56/6/10
Sex[2]	1, 0, 2	1, 0, 1	0, 0, 1	6, 0, 0	3, 0, 2	7, 3, 1	4, 1, 0	6, 3, 1
Mean RAI (SE)	0.207 (0.116)	0.308 (0.205)	0.141 (0.099)	3.490 (1.864)	4.202 (1.251)	3.215 (0.714)	4.023 (0.889)	3.626 (1.048)
Range RAI	0 - 1.185	0 – 1.538	0 - 1.786	0 - 2.712	0 – 13.636	0 – 12.500	0 – 10.145	0 – 14.773
% Detections	14.3	20.0	9.1	58.3	64.3	82.4	81.8	42.9

[1] C/R/N (C: nº captures, R: nº recaptures, N: nº individuals)

[2] Sex (Male, Female, Unknown)

Table 2.3- Results of the closure test for the closed population assumption, abundance and density estimates for 5 camera traps sessions in Santa Fé Ranch (Central Brazil) using the jackknife population model M(h), in which capture probabilities vary by animal because of differences in sex, age, social dominance and activity level.

Year	Season	Abundance ±SE	95% confidence interval	Closure Test		Area sampled (km²)	Buffer: ½ MMDM (km) ± SE	Density (per 100km²) ± SE	p-hat
				z	P				
2005	Dry	6 ± 2.43	6 - 21	1.48	0.90	117	2.52±2.35	5.15±4.14	0.229
2006	Wet	8 ± 3.19	7 - 23	-1.21	0.11	158	3.31±2.58	5.06±3.77	0.196
	Dry	13 ± 3.03	12 - 28	-0.32	0.38	136	2.67±2.27	9.56±6.88	0.162
2007	Wet	6 ± 1.31	6 - 12	-0.73	0.38	120	3.69±0.84	5.01±1.20	0.381
	Dry	7 ± 2.69	7 - 22	0.82	0.79	215	4.38±2.56	3.26±2.37	0.143

2.3.3- Jaguar presence and abundance Models

The most parsimonious model for jaguar presence included place and richness of species with a probability of selection of 0.51 (as well as number of days, which we retained in every model, Table 2.4). Models that included place and season presented a selection probability of 0.21 and 0.28. Place variable (ie, if the camera was set on a road or a trail) was part of all models of jaguar occurrence selected according to AIC scores (Table 2.4). The probability of detecting jaguars in roads was 6 times higher than in trails (P_{roads} = 0.6968; P_{trails} = 0.1038). Jaguar presence also presented a positive association with the richness of vertebrate species recorded (Table 2.5).

Table 2.4- Summary of models for predicting jaguar presence and relative abundance in central Brazil according to four different hypotheses on the factors potentially affecting them (*significant at 0.05; **significant at 0.01;*** significant at 0.001).

	Model	AIC	Deviance	ΔAIC	wAIC
	Jaguar presence				
1A	*Null Model*	171.4	167.4	41.8	0.00
	Sampling Variables				
1B	Days+Season+Place***	131.4	121.4	1.8	0.21
1C	Days+Place***	130.8	122.8	1.2	0.28
	Food Variables				
1D	Days+Richness*+Distm_water*+Peccary*	149.9	137.9	20.3	0.00
	Shelter/Human perturbation				
1E	Days+Area**+Dist_road*	144.5	134.5	15.9	0.00
	Combining Variables				
1F	Days+ Richness +Place***	129.6	117.9	0	0.51
	Jaguar abundance				
2A	*Null Model*	96.5	92.5	28.29	0.00
	Sampling Variables				
2B	Days**+Year*+ Area*	78.7	68.7	10.49	0.00
	Food Variables				
2C	Days+ Richness***+Prey_Biomass	70.06	60.06	1.85	0.14
	Human disturbance				
2D	Days**+Area**	82.93	74.93	14.72	0.00
	Combining Variables				
2E	Days+Area*+Year+Dist_River*+ Richness**	68.21	54.21	0	0.36
2F	Days+Area*+ Richness**	69.53	59.53	1.32	0.50

In the analyses of factors that influence the number of photos of jaguar per camera station (jaguar relative abundance) data fitted most adequately a model that included area, richness of species and distance to river, with a selection probability of 0.50 (and, again, number of days, Table 2.4). Other suitable candidate models were the one including area and richness of species (with probability of selection of 0.36), and another one including richness of species and prey biomass index (BAI) (with a selection probability of 0.14, Table 2.4). Richness of species was present in all these models, being always significant ($P < 0.01$, Tables 2.4 and 2.5). Parameter estimates reveal the importance of area as predictor, indicating that jaguar abundance was higher outside the park (the photographic rate was an order of magnitude higher in the ranch, Table 2.5). We also found a negative influence of distance to the river on jaguar relative abundance (Table 2.5). Place is not relevant in the analyses of abundance because we used only those stations with at least one photograph, thus including mostly stations located at roads.

Table 2.5- Estimated coefficients (± standard error) for the variables of the two best models for jaguar presence and relative abundance in central Brazil (parameter estimate significant at * 0.05; ** 0.01;*** 0.001 levels).

Variables	**Jaguar presence**		**Jaguar relative abundance**	
	Model 1C	*Model 1F*	*Model 2E*	*Model 2F*
Intercept	0.0707±0.7366	0.0555±0.7185	-0.0279±0.0272	-0.4985±0.5678
Days	0.0135±0.0119	0.0041±0.0126	0.0019±0.0057	0.0027±0.0059
Area			1.0670±0.4487*	0.8582±0.4578*
Place	-3.1523±0.5320***	-2.8929±0.5239***		
Year			0.1393±0.1358	
Richness of Species		0.1255±0.0722	0.0750±0.0247**	0.0898±0.0229***
Distance to River			-0.00004±0.00001*	

2.4- Discussion

This study offers the first information on jaguar density in the Brazilian Amazon region, an important area lacking data on the status of the species (Sanderson et al., 2002). In our study, jaguar density was higher than in other study sites in the Amazonian rainforest (e.g. Bolivia, Table 2.6) and it is one of the highest values estimated so far for Brazil, with an average of 5.6 individuals/100km^2 (3.3 - 9.6 individuals /km^2), being higher than densities from *Caatinga*, *Cerrado* and Atlantic forest biomes (<3 individuals /km^2, Table 2.6). Only the estimates from the Pantanal are higher (>10 individuals /km^2). Our estimates are also similar to other areas of South and Central America (Table 2.6).

We did not expect drastic variations in the population numbers during our three years of sampling and consequently a major overlap in the confidence intervals of our density estimates between years and seasons was anticipated. This was confirmed in jaguar capture rate (RAI) but not for the density estimate of 2006 dry season (Table 2.3). The number of animals captured during 2006 dry season was higher and since the sampled area was within the range for other years, we believe the increased effort (number of camera-stations and sampling period) contributed to the higher estimate (Wegge et al., 2004). The lower density estimate in 2007 dry season, even if not significant, could be associated to a considerable larger sampled area, a direct consequence of higher MMDM due to an increase in camera spacing (2.974 km for 2007 dry season survey comparing to an average of 1.576 km in other surveys; Wegge et al., 2004).

Jaguar presence and abundance can be influenced by both biological and methodological constrains (Maffei and Noss 2008; Paviolo et al., 2007; Salom-Pérez et al., 2007). On a local level, jaguars show a positive selection for roads (Maffei et al., 2004) as confirmed by our data. We found that area (park or ranch) entered only the model for jaguar presence that considered human perturbation. Therefore, the lower probability of presence inside the park can be interpreted as associated to other variables such as a lower density of roads or a lower mean richness (on average 5.3 and 2.0 species detected in SF-Ranch and in CS-Park, respectively). However, in the case of relative density, area entered in the final models together with richness. Therefore the ranch was a better place for jaguars than the park. The main environmental difference between both we can think off in association to this difference in habitat quality is the large scale flooding that occurs seasonally in the park in comparison with the spatially restricted flooding of the ranch, maybe affecting food resources or simply altering the preference of jaguars.

Table 2.6- Jaguar density estimated from camera trapping in different studies areas throughout its range in South and Central America (surveyed area was determined using ½ MMDM buffer strip).

Country	*Study Site*	*Density (SE) ind/100 km²*	*Surveyed area km²*	*References*
Brazil	Amazonian Rainforest	3.26/9.56 (2.37/6.88)	117 - 215	This Study
	Cerrado	2.00	500	Silveira, 2004
	Atlantic Forest	2.22 (1.33)	300	Cullen et al., 2005
	Pantanal	10.3/11.7 (1.53/1.94)	274 - 360	Soisalo and Cavalcanti, 2006
	Caatinga	2.67 (1.06)	524	Silveira et al., in press
Argentina/ Brazil	Atlantic Forest	1.46 (0.34)	958	Paviolo et al., 2008
	Atlantic Forest	0.86 (0.3)	577	Paviolo et al., 2008
Argentina	Atlantic Forest	0.27	368	Paviolo et al., 2008
	Atlantic Forest	0.2	1001	Paviolo et al., 2008
Belize	Broadleaf Tropical Forest	8.80 (2.25)	159	Silver et al., 2004
	Broadleaf Tropical Forest	7.48 (2.74)	107	Silver et al., 2004
Bolívia	Amazonian Rainforest	2.84 (1.78)	458	Silver et al., 2004
	Tropical dry forest (*Chaco*)	5.11 (2.10)	137	Silver et al., 2005
	Tropical dry forest (*Chaco*)	3.93 (1.30)	272	Silver et al., 2006
	Tropical dry forest (*Chaco*)	3.41 (1.21)	128 - 309	Maffei et al., 2004
	Amazonian Rainforest	1.68 (0.78)	170	Wallace et al., 2003
México	Tropical rainforest	1.82/6.18 (0.17/0.33)	49 -183	Faller et al., 2007
Costa Rica	Tropical rainforest	6.98 (2.36)	86	Salom-Pérez et al., 2007

Food resources influence carnivore abundance and could be a reasonable explanation for differences in density between places. However, prey biomass did not enter in the final models, while it might well be that richness is a better surrogate for food resources than our prey biomass index.

The jaguar is considered an opportunistic predator that exploits prey according to availability (Rabinowitz and Nottingham, 1986). The analysis of scats in our study site confirmed this plasticity observing, nevertheless, a larger contribution of larger prey (tapir, deer, cattle, peccary) to the overall biomass consumption (Nuno, 2007). Despite its diet plasticity, the jaguar is considered to have a positive selective tendency towards collared peccaries (*Pecari tajacu*, Weckel et al., 2006). The analysis of the factors affecting presence and abundance of jaguar seems to corroborate this generalist exploitation of food resources since richness of species was strongly correlated with both and also, to a lesser extent, with prey biomass and peccary presence.

Our results, hence our interpretations, could be biased by methodological problems. The use of 1/2MMDM can contribute to bias the estimate of sampled area and, together with low catchability (p-hat less than 0.03), could cause an overestimation of density (Maffei and Noss 2007; Soisalo and Cavalcanti, 2006; White et al., 1982). However, it only affects the actual density estimates, and, as previous studies follow the same approach, the differences observed when comparing between studies cannot be directly attributed to it. The interpretation of the analysis of the factors affecting jaguar density rests on the assumption that our relative density (number of photos) is a good surrogate for absolute density. Over 60% of the camera locations that registered jaguar presence had more than one photo. The fact that there was a good correlation between the average number of different individuals shot at each camera site and the total number of jaguar shots in the same site (r = 0.74) allows us to use the number of jaguar photos as a surrogate for abundance (Carbone et al., 2001).

Our results come only from a single site (of more than 1500 km^2 with more than 300 km^2 effectively sampled), but we think they offer an idea of the role of the Amazon as the main reservoir for the jaguar. We found that jaguar abundance was higher in the neighbouring private land that in the protected area, which, under the present scenario of growing anthropogenic disturbance within the Amazon basin, shows how important it is to manage private reserve forests (Heines et al. 2006). Additionally, we should also acknowledge that the network of protected areas alone probably does not ensure preservation of many large mammalian species in the long-term (Azevedo-Ramos et al., 2006; Soares-Filho et al., 2006). The large tracts of forest set aside inside private farms and ranches, following the current legislation in Brazil, can aid in the conservation of the jaguar if the connectivity of forested areas is maintained. However, these fragments are commonly encroached by human activities (hunting and logging), sold to third parties for further development or occupied by landless farmers. As a result the amount of forest retained inside farms goes below the required legal limit of 80% and its quality can be strongly reduced. All these uncontrolled, or illegal activities put the usefulness of reserves within farms at risks and fully dependent on the will of landowners. Therefore we encourage the enforcement of long term conservation of the legally required private forest reserves within farms at the Amazon agricultural frontier. Additionally, we need to obtain demographic parameters (mostly survival data) to evaluate the existence of administrative edge effects (Revilla et al., 2001) in private reserve forests due to the selective killing of jaguars aimed at reducing damages to livestock.

We found that jaguar relative density was well correlated with the total richness of species photographed at the stations. Many of these species are large vertebrates, mostly mammals and birds, catalogued under some risk category due to forest loss and hunting. Therefore, the social interest in preserving jaguars, which as all other large wildcats are very attractive to the general public, could be used as an umbrella to preserve many other species of less charismatic vertebrates in the Amazon.

Current efforts in jaguar conservation are constrained by a lack of reliable data on the distribution, densities and trends of its populations. The deficient data available for the Amazon, an area that includes a considerable amount of its range (Sanderson et al., 2002), together with the suspected low suitability of this region (IUCN et al, 2008) show how important are studies contributing to evaluate accurately the status of populations at local and regional levels to determine priorities and an effective conservation planning under different scenarios of land use in the Amazon agricultural frontier.

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References

Azevedo-Ramos, C., Domingues Do Amaral, B., Nepstad, D.C., Soares-Filho, B. and Nasi, R., 2006. Integrating Ecosystem Management, Protected Areas, and Mammal Conservation in the Brazilian Amazon. Ecology and Society 11:17. [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art17/

Bates, D., Sarkar, D., 2006. Lme4: linear mixed-effect models using S4 classes, <http://www.R-project.org>.

Carbone, C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J.R., Griffiths, M., Holden, J., Kawanishi, K., Kinnaird, M., Laidlaw, R., Lynam, A., Macdonald, D.W., Martyr, D., McDougal, C., Nath, L., O'Brien, T., Seidensticker, J., Smith, D.J.L., Sunquist, M., Tilson, R. and Shahruddin W.N., 2001. The use of photographic rates to estimate densities of tigers and other cryptic mammals. Animal Conservation 4, 75-79

Crawley, M.J., 2002. Statistical computing: An introduction to data analysis using S-Plus. Hoboken (New Jersey). John Wiley and Sons. 772 pp.

Cullen Jr,L., Abreu, K.C., Sana, D. and Nava, A.F.D., 2005. Jaguars as landscape detectives for the upper Paraná River corridor, Brazil, Natureza and Conservação 3, 147–161.

DiBitetti, M.S, Paviolo, A. and DeAngelo, C., 2006. Density, habitat use and activity patterns of ocelots (*Leopardus pardalis*) in the Atlantic forest of Misiones, Argentina. Journal of Zoology, London 270, 153–163

Dillon, A. and Kelly, M.J., 2007. Ocelot *Leopardus pardalis* in Belize: the impact of trap spacing and distance moved on density estimates. Oryx 41, 469–477.

Faller, J.C., Chávez, C., Johson, S. and Ceballos, G., 2007. Densidad y tamaño de la población de jaguar en el noroeste de la península de Yucatán. In: Ceballos, G., Chávez, C., List, R., Zarza, H. (Eds.), Conservación y Manejo del Jaguar en México: estudio de caso y perspectivas. Conabio-Alianza WWF/Telcel-Universidad Nacional Autónoma de México, México, pp. 111-121.

FAO, 2006. Global Forest Resources Assessment 2005: Progress towards sustainable forest management. Food and Agriculture Organization, United Nations, Rome, Italy.

Giglio, L., Csiszar, I. and Justice, C.O., 2006. Global distribution and seasonality of active fires as observed with the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. Journal of Geophysical Research 111, G02016, doi:10.1029/2005JG000142.

Heines, A.M., Janecka, J.E., Tewes, M.E., Grassman Jr.L.I. and Morton, P., 2006. The importance of private lands for ocelot *Leopardus pardalis* conservation in the United States. Oryx 4, 90-94.

IUCN, Conservation International, Arizona State University, Texas AandM University, University of Rome, University of Virginia, Zoological Society London. 2008. An Analysis of Mammals on the 2008 IUCN Red List <www.iucnredlist.org/mammals>. Downloaded on 9 October 2008.

Karanth, K.U., Chundawat, R.S., Nicholds, J.D. and Kumar, N.S., 2004. Estimation of tiger densities in the tropical dry forest of Panna, Central India, using photographic capture-recapture sampling. Animal Conservation 7, 285-290.

Karanth, K.U. and Nicholds, J.D., 1998. Estimating tiger (*Panthera tigris*) populations form camera-trap data using capture-recaptures. Ecology 79, 2852-2862.

Karanth, K.U. and Nicholds, J.D., 2002. Monitoring tigers and their prey. A Manual for researchers, managers and conservationists in Tropical Asia. Center for Widlife Studies. Bangalore. 193 pp.

Kawanishi, K. and Sunquist, M.E., 2004. Conservation status of tigers in a primary rainforest of Peninsular Malaysia. Biological Conservation 120, 329-344.

Kelly, M.J., Noss, A.J., Bitetti, M.S., Maffei, L. and Arispe, R.L., 2008. Estimating puma density from camera trapping across three study sites: Bolivia, Argentina, and Belize. Journal of Mammalogy 89, 408–418.

Maffei, L., Cuellar, E. and Noss, A., 2004. One thousand jaguars (*Panthera onca*) in Bolivia's Chaco? Camera trapping in the Kaa-Iya National Park. Journal of Zoology, London 262, 295-304.

Maffei, L. and Noss, A., 2008. How small is too small? Camera trap survey areas and density estimates for ocelots in the Bolivian Chaco. Biotropica 40, 71-75.

Morton, D.C., DeFries, R.S., Shimabukuro, Y.E., Anderson, L.O., Arai, E., Espirito-Santo, F., Freitas, R. and Morisette, J., 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceedings of the National Academy of Sciences 103, 14637-14641.

Nowell K. and Jackson P., 1996. Wild Cats: Status survey and conservation action plan. International Union for Nature Conservation (IUCN) /Cat Specialist Group, Gland, Switzerland, 382 pp.

Nuno, A., 2007. Conserving Carnivores: A. Attitudes of Portuguese high school students towards carnivores. B. Feeding habits of the jaguar: local and regional perspectives. MSc Dissertation. University of Leeds, 105 pp.

O´Brien, T., Kinnard, M.F. and Wibisono, H. T. 2003. Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. Animal Conservation 6, 131-139.

Otis, D.L., Burnham, K.P., White, G.C. and Anderson, D.R., 1978. Statistical inference from capture data on close population. Wildlife Monographs. 62, 1-135.

Paviolo, A., De Angelo, C.D., Di Blanco, Y.E. and Di Bitetti, M.S., 2008. Jaguar *Panthera onca* population decline in the Upper Paraná Atlantic Forest of Argentina and Brazil. Oryx 42, 554-561.

Pierce, B.M., Bleich, V.C. and Bowyer, R.T., 2000. Social organization of mountain lions: Does a Land-Tenure system regulate population size? Ecology 91, 1533-1543.

Rabinowitz, A.R. and Nottigham, B.G., Jr., 1986. Ecology and behaviour of the jaguar (*Panthera onca*) in Belize, Central America. Journal of Zoology, London 210, 149-159.

Revilla, E., Palomares, F. and Delibes, M., 2001. Edge-core effects and the effectiveness of traditional reserves in conservation: Eurasian badgers in Doñana National Park. Conservation Biology 15, 148-158.

Rexstad, E. and Burnham, K.P., 1991. User's guide for interpretative program CAPTURE. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University. Fort Collins, CO.

Salom-Pérez, R., Carrillo, E., Sáens, J.C. and Mora, M., 2007. Critical condition of the jaguar in Corcovado National Park, Costa Rica. Oryx, 41, 51-56.

Sanderson, E.W., Redford, K.H., Chetkiewicz, C.B., Medellin, R., Rabinowitz, A., Robinson, J. and Taber, A., 2002. Planning to save a species: the jaguar as a model. Conservation Biology 16, 58–72.

Sick, H., 1997. Brazilian Ornithology (from Portuguese). Editora Nova Fronteira, Rio de Janeiro. 912 pp.

Silveira, L., 2004. Ecologia comparada e conservação da onça-pintada (*Panthera onca*) e onça-parda (*Puma concolor*), no Cerrado e Pantanal. PhD thesis, University of Brazilia, Brazil. 240 pp.

Silveira, L., Jácomo, A.T.A. and Diniz-Filho, J.A.F., 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114, 351-355.

Silveira, L., Jácomo, A.T.A., Astete, S., Sollmann, R., Tôrres, N.M., Furtado, M.M. and Marinho-Filho, J., (in press). Jaguar density in the Caatinga of Northeastern Brazil. Oryx.

Silver, S.C., 2004. Assessing Jaguar abundance using remotely triggered cameras. Wildlife Conservation Socitey. 25 pp.

Silver, S.C., Ostro, L.E., Marsh, L.K., Maffei, L., Noss, A.J., Kelly, M.J., Wallace, R.B., Gómez, H. and Ayala, G., 2004. The use of camera traps for estimating jaguar *Panthera onca* abundance and density using capture/recapture analysis. Oryx 38, 148-154.

Soares-Filho, B.S., Nepstad, D.C., Curran, L.M., Cerqueira, G.C., Garcia, R.A., Ramos, C.A., Eliane, V., McDonald, A., Lefebvre, P. and Schlesinger, P., 2006. Modelling conservation in the Amazon basin. Nature, 440, 520-523.

Soisalo, M.K. and Cavalcanti, S.M.C., 2006. Estimating the density of a jaguar population in the Brazilian Pantanal using camera-traps and capture-recapture sampling in combination with GPS radio-telemetry. Biological Conservation 129, 487-496.

Stanley, T.R. and Burnham, K.P., 1999. A closure test for time-specific capture-recapture data. Environmental and Ecological Statistics 6, 197-209.

Swank, W.G., Teer, J.G., 1989. Status of the jaguar. Oryx 23, 14–21.

SPMA- Secretaria de Planejamento e Meio Ambiente, 2000. Avaliação ecológica rápida do Parque Estadual do Cantão. Governo do Estado do Tocantins, Palmas, Tocantins, Brazil, 133 pp.

Wallace, R.B., Gomez, H., Ayala, G. and Espinoza, F., 2003. Camera trapping for jaguar (*Panthera onca*) in the Tuichi Valley, Bolivia. Mastozoological Neotropical 10, 5–11.

Weber,W. and Rabinowitz, A., 1996. A global perspective on large carnivore conservation. Conservation Biology 10, 1046–1054.

Weckel, M. Giuliano, W. and Silver, S., 2006. Jaguar (*Panthera onca*) feeding ecology: Distribution of predator and prey through time and space. Journal of Zoology, London 270, 25-30.

Wegee, P., Pokheral, C.P., Jnawali, S.R., 2004. Effects of trapping effort and trap shyness on estimates of tiger abundance from camera trap studies. Animal Conservation 7, 251-256.

White, G.C., Anderson, D.R., Burnham, K.P. and Otis, D.L., 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos, National Laboratory Publication LA-8787-NERP, Los Alamos, New Mexico, USA

"What is man without the beasts? If all the beasts were gone, man would die from a great loneliness of spirit. For whatever happens to the beasts, soon happens to man. All things are connected."

Chief Seattle

CHAPTER 3

One or two cameras per camera-trapping station? Estimating jaguar density in the Amazon

One or two cameras per camera-trapping station? Estimating jaguar density in the Amazon

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Abstract

Terrestrial carnivores are nocturnal, solitary and present naturally low densities. To overcome difficulties in monitoring carnivore populations techniques like camera trapping have arise, and due to its effectiveness is now commonly used to determine carnivore densities. There are still some issues and to overcome limited resources, researchers look for a compromise that ensures both efficiency and precision on collected data. We used data from capture-recapture study in a forested area in central Brazil to evaluate the use of one versus two cameras (Set 1 and Set 2) per station in determine species Capture rate (RAI) and jaguar (*Panthera onca*) density. Also we intended do evaluate jaguar use of different types of trails (roads and human made trails). Species capture rate recorded with one camera (Set 1 or Set 2) was inferior that using both cameras together, but not significantly (Chi-square$_{set1}$=0.2042; p=0.651 and Chi-square$_{set2}$ =0.029; p=0.865). Number of jaguars that were identified using photos collect with one camera (Set 1 and Set 2) ranged between 6 and 7 animals but reached 10 individuals when analysing photos from both cameras pull together. These differences resulted in lower densities estimates of jaguar when using one camera (1.24 to 3.26 jaguars/100 km^2) comparing to two cameras (3.99 jaguars/100 km^2). Jaguars seem to avoid human made trails and in contrast exploited different types of roads (low and high used) according to its availability. Based on our results we recommend the use of two cameras per station for jaguar density monitoring and a sampling design based on uniform, even spaced cameras set on roads or large open trails, based on further knowledge on jaguar territoriality on Amazon biome.

Key words: central Brazil, camera-trapping, density estimation, individual identification, CAPTURE software, *Panthera onca*.

3.1- Introduction

The use of camera trapping to study different aspects of animal ecology has been popularized in recent times due to its relative efficiency in obtaining relevant data (Kelly, 2008; Rowcliffe and Carbone, 2008). The application of camera trapping is nowadays considered a standard tool in both conservation biology and ecology, been commonly applied in species surveys, abundance estimation, nest depredation studies, estimates of vital rates for population management and conservation assessment studies (Karanth, 1995; Hernandez et al., 1997; Silveira et al., 2003; Trolle, 2003; Trolle and Kéry, 2005; Johnson et al., 2006; Karanth et al., 2006; Linkie et al., 2006; Dillon and Kelly, 2007; Rowcliffe and Carbone, 2008; Tobler et al., 2008).

One of the most common uses of camera trapping is to determine the relative or absolute density of elusive species. The former is usually based on photographic capture rate, i.e. number of photos/effort (O'Brien et al., 2003). The latter uses a capture-recapture statistical framework (Karanth and Nicholds, 1998; Stanley and Burnham, 1999) considering several premises: animals must present marks (spots, stripes, scars or artificial tags) allowing individualization, all animals present in the study area must have some detection probability, sampling time should be short (typically one or a few months) to secure close population status and sampling design should maximize capture rate (Karanth, and Nichols, 1998, 2002; Silver et al., 2004; Rowcliffe and Carbone, 2008).

To overcome limited resources, researchers look for a compromise that ensures both efficiency and precision on collected data. A combined strategy that manages the number of trap stations (one/two cameras per station) and the sample area (distance between camera stations and/or several blocks of stations sampled consecutively) has been applied in the majority of cases (e.g. Karanth, and Nichols, 2002; O'Brien *et al.*, 2003; Dillon and Kelly, 2008). However, there is still some debate concerning the protocol, particularly regarding trap distance and sampling area estimation (Soisalo and Cavalcanti, 2006; Dillon and Kelly, 2007; Maffei and Noss, 2008), with few studies looking at the consequences of different designs in the results (Harmsen, 2006; Dillon and Kelly, 2007; Maffei and Noss, 2008).

The jaguar *Panthera onca* (Linnaeus, 1758) is the largest cat in the American continent and presents a large distribution area that stretches from the Southern US/ Mexico to Northern Argentina. The elusive nature of this species makes it difficult to detect and monitor (Rabinowitz and Nottingham 1986). In the last decade the use of remote triggered photographic cameras has made a strong contribution to the increase in information on jaguar density and biology (Silver, 2004; Silver et al., 2004). However, its population status remains unknown throughout the majority of its range and the declining status impairs the research focused on population dynamics that forms the base for conservation guidance (Karanth et al., 2003; Sanderson et al., 2002).

Taking into consideration that knowing the species density per se is not enough to evaluate population stability or set up conservation policies (Harmsen, 2006) we intend to establish a protocol of long-term monitoring of jaguar density and its prey using camera trapping. Given that biases on abundance estimates are usually associated with methodological constrains and absence of information on local species biology, in this study we aim at improving the photo-trapping protocol by looking at the relative cost-efficiency of using one or two cameras per trap station. Specifically, we want to know how this affects 1) the photographic–rate for most common large and medium size species in the study area and 2) the density estimates for the jaguar. Also, we intended to determine the jaguar use of trails (roads and human-made) versus its availability and possible "trap-shyness" that could condition results.

3.2- Material and Methods

3.2.1-Study area

The study was carried within Santa Fé Ranch (09°34'S, 50°21'W), a 65.000 ha beef cattle ranch in the southeast Pará State (southern border of the Amazon in Central Brazil), within the Araguaia River basin. Fieldwork was done in a continuous patch of semi-deciduous tropical forest that covers the majority of the ranch (65%) margining the Araguaia River and that constitutes the farm forest reserve (obligatory by Brazilian legislation). The central area of the farm is occupied by grazed pasture and human infrastructures (houses and offices). The climate presents a strong seasonality, with a characteristic rainy season from October to March and a dry season between April and September.

3.2.2-Sampling

The study was conducted during September-November 2007 in the forest reserve of the Santa Fé Ranch (SRF). The sampling consisted in 21 trap stations placed in two dirt roads (one with frequent human use and another with low human use) and four human made trails (opened 4 months earlier). Distance between stations was less than 3.6 Km to ensure that all jaguars in the sampled area had some probability of capture (assuming a minimum home range size of a jaguar about 10 km^2, Rabinowitz and Nottigham, 1986; Karanth and Nicholds, 2002; Silver, 2004; Silver *et al*, 2004). Each station consisted of two passive infrared camera traps, model C1-BU (Vibrashine Inc., Taylorsville, MS 3968, USA) set at approximately 50-70 cm from the ground (Silver, 2004). The cameras were placed on each side of the roads/trails, facing each other with a difference of about half a meter to avoid flash influence between them (Karanth, 1995), and were programmed to take photographs 24h/day with a 5-min interval between photos. The state of film and battery at each station was checked on a regular basis (15-20 days) throughout the 90 days survey period. Each camera was classified as belonging to Set 1 or Set 2 according to established preference order depending on direct sunlight exposition and distance to the path (Set 1 represented the first choice in case of only one camera available per location).

3.2.3- Data Analysis

Species and individual identification (when possible), number of individuals, date and hour were determined for each photograph. We considered photos as independent events for each species when taken more than 1 hour apart or if different individuals could be identified (O'Brien et al., 2003). We calculate a relative abundance index (RAI) for all species by dividing the number of independent captures by effort (trap-nights) times 100 (O'Brien et al., 2003; Kawanishi and Sunquist, 2004). We used linear regression to measure similarity between main species photographic-rates (i.e. species with a total of ≥ 5 photographs) obtained using one (Set 1 and Set 2) and two cameras per station (both sets together). Similar photographic rates for the different sets will have an intercept estimate of 0 and a slope of 1, while departures from this null prediction will indicate a bias in capture rates.

Jaguar numbers were estimated by identifying individuals by their pattern of spots in two different ways: for data collected within single camera sets (Set 1 and 2) we recognized animal identity by their left and right flanks separately; while in the double camera set we pooled data from both cameras and did an individual identification using both flanks simultaneously. We built a total of 5 capture-recapture matrix histories (two for Sets 1 and 2: right and left flanks and one for double camera set). We used the program CAPTURE to determine jaguar population abundance (Otis et al., 1978; Rexstad and

Burnham, 1991). We combined the total number of sampling days in 10-days sampling sections for the entire capture-recapture matrices. We used the jackknife estimation model (M_h) to determine the number of individuals, hence assuming that each individual has a unique capture probability due to territoriality and behaviour. This assumption is regarded as the most biologically plausible for large felids (Karanth and Nichols, 1998).

The standard method applied in jaguar density estimates obtained with camera trapping measures effective sampled area by using a buffer strip estimated with half the Mean Maximum Distance Moved by all the individuals recaptured (½ MMDM) when home range information for the species in the study area is not available (Wallace et al., 2003; Maffei et al., 2004; Silver et al., 2004; Soisalo and Cavalcanti, 2006; Salom-Pérez et al., 2007; Paviolo et al., 2008). Recent work combining camera-trap and radio-tracking data revealed that using ½ MMDM could lead to density overestimation, and proposing the use of full MMDM as a less biased approximation (Soisalo and Cavalcanti, 2006; Dillon and Kelly, 2008). Moreover Balme et al. (2009) compared the use of both full MMDM and ½ MMDM for leopard density estimates in South Africa and verified that the second performed better based on known population data. Consequently, and for comparison reasons, both full MMDM and the ½ MMDM (using data from all recapture individuals within each capture history) were computed to calculate a sampled area by buffering each trap station with the corresponding estimate (Karanth and Nicholds, 2002; Silver, 2004; Soisalo and Cavalcanti, 2006; Salom-Pérez et al., 2007, Balmer et al., 2009).

3.3-Results

3.3.1- Photographic Rate

With a sampling effort of 1681 camera-nights we obtained a total of 724 photographs in which we could identify the species, including mammals (n = 505), birds (n = 215) and reptiles (n = 1), plus three unidentified photos. The crab-eating fox was the most common species photographed followed by the bare-faced curassow, the jaguar and the puma (both with RAI = 4.08) (Table 3.1). The red brocket deer and the tapir presented the highest capture rates between jaguars' main prey species. The capture rates obtained with only one camera (either Set 1 or 2) did not differ (Fig. 3.1), showing that our a priori identification of Set 1 as the most favourable side of the station was unjustified. However, we consistently obtained higher rates using two cameras per station (χ^2 = 555.9, P < 0.0001, Table 3.1, Fig. 3.1), with overall rates of 2.14±0.12 and 1.85±0.12 for sets with two and one camera, respectively. On average there was an increase of 31% in capturing rate when using two cameras. No correlation was found between differences in capture rate and abundance (total RAI) or species weight.

Table 3.1 – Number of independent photos (photographic rate-RAI) of main species captured with one (Set 1 and Set 2) and two cameras (Total) in 1681 trap-nights at Santa Fé Ranch, central Brazil (in bold is highlights which of the two sets has obtain more photos for each species).

		SET 1	SET 2	TOTAL
MAMMALS	Tapir, *Tapirus terrestris*	**43 (2.74)**	40 (2.55)	54 (3.45)
	Gray Brocket Deer, *Mazama gouazoupira*	**13 (0.83)**	12 (0.77)	16 (1.02)
	Red Brocket Deer, *Mazama americana*	47 (3.00)	**49 (3.13)**	63 (4.02)
	Collared Peccary, *Pecari tajacu*	**27 (1.72)**	16 (1.02)	35 (2.23)
	Crab-eating fox, *Cerdocyon thous*	**82 (5.23)**	52 (3.32)	108 (6.89)
	Margay, *Leopardus wiedii*	2 (0.13)	**4 (0.26)**	5 (0.32)
	Ocelot, *Leopardus pardalis*	17 (1.09)	**19 (1.21)**	22 (1.40)
	Puma, *Puma concolor*	34 (2.17)	**53 (3.38)**	64 (4.08)
	Jaguar, *Panthera onca*	45 (2.87)	**52 (3.32)**	64 (4.08)
	Tayra, *Eira barbara*	**5 (0.32)**	2 (0.13)	6 (0.38)
	South American Coati, *Nasua nasua*	**11 (0.70)**	9 (0.57)	14 (0.89)
	Azara's Agouti, *Dasyprocta azarae*	**12 (0.77)**	7 (0.45)	15 (0.96)
	Capybara, *Hydrochaeris hydrochaeris*	6 (0.38)	**7 (0.45)**	7 (0.45)
	Giant Armadillo, *Priodontes maximus*	3 (0.19)	3 (0.19)	5 (0.32)
	Nine-banded Armadillo, *Dasypus novemcinctus*	4 (0.26)	**6 (0.38)**	8 (0.51)
BIRDS	Guan, *Penelope* sp.	**27 (1.72)**	26 (1.66)	42 (2.68)
	Bare-faced Curassow, *Crax fasciolata*	59 (3.77)	**84 (5.36)**	104 (6.64)
	Razor-Billed Curassow, *Mitu tuberosa*	26 (1.66)	**31 (1.98)**	47 (3.00)

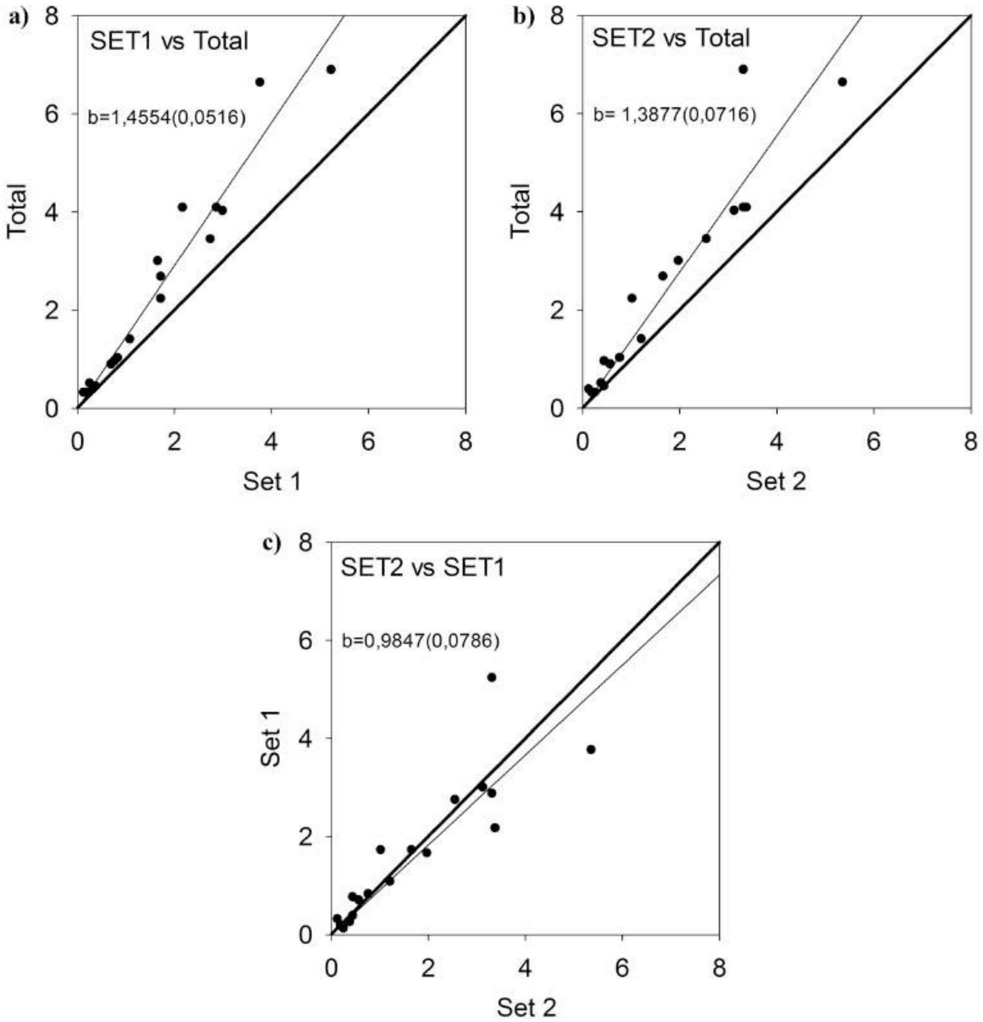

Figure 3.1. Cross-species comparison of overall photographic rates (records/100 trap-nights) using one camera (Set 1 and Set 2) and both cameras (total) per station. The fine line indicates regression of the different sets' photographic rates, while the thick line indicates the expected regression if both estimate similar rates (i.e. a=1).

3.3.2- Jaguar Numbers and Density

We could not reject the closure assumption for any of capture-recapture histories. The estimated average capture probabilities (p-hat) ranged from 0.143 to 0.242 (Table 3.2). The number of jaguars identified using the photos obtained with only one camera (Set 1 or Set 2) was 6-7 animals, reaching 10 individuals when analysing photos from both cameras simultaneously (Table 3.2). The population estimates computed by the M_h model was between 4 and 7 individuals (mean 5.5) when using only one camera per station, which corresponds to less than half of the value obtained when using both cameras (N = 12 ± 3.20, Table 3.2). The estimates of the buffer strip width did not differ when using one (average MMDM = 12 ± 4.06 km; Min = 8.76 ± 5.12, Max = 14.39 ± 3.55) or two cameras (MMDM = 11.4 ± 4.01km) (Kruskal-Wallis K = 4.585, *P* = 0.3326). Jaguar densities estimated using data from one single camera varied from 1.24 to 3.26 jaguars/100 km^2, reaching 3.99 jaguars/100 km^2 when using trapping stations with two simultaneous cameras (Table 3.2, Fig. 3.2).

Table 3.2. Results of the closure test for the closed population assumption, number of jaguars identified from camera trapping, abundance, buffer strip size and density estimates for each capture history using the jackknife population model M(h) in CAPTURE program.

Camera	Side	p-hat	Nº jaguar identified	Abundance ±SE	95% confidence interval	Closure Test		MMDM		½ MMDM	
						z	P	Buffer (km) ±SE	Density (per 100km^2) ± SE	Buffer (km) ±SE	Density (per 100km^2) ± SE
SET1	**Right**	0.167	7	6±1.86	5-13	1.71	0.96	14.39±3.55	0.56±0.28	7.20±1.78	1.48±0.64
	Left	0.229	6	5±2.39	5-21	0.68	0.75	10.88±3.63	0.71±0.48	5.44±1.82	1.77±1.08
SET2	**Right**	0.143	7	7±2.70	7-22	0.82	0.79	8.76±5.12	1.32±1.16	4.38±2.56	3.26±2.37
	Left	0.156	7	4±1.34	4-10	0.82	0.79	12.00±3.90	0.49±0.29	6.00±1.95	1.24±0.63
BOTH		0.242	10	12±3.20	11-29	-1.03	0.15	11.40±4.01	1.59±0.91	5.70±2.00	3.99±1.86

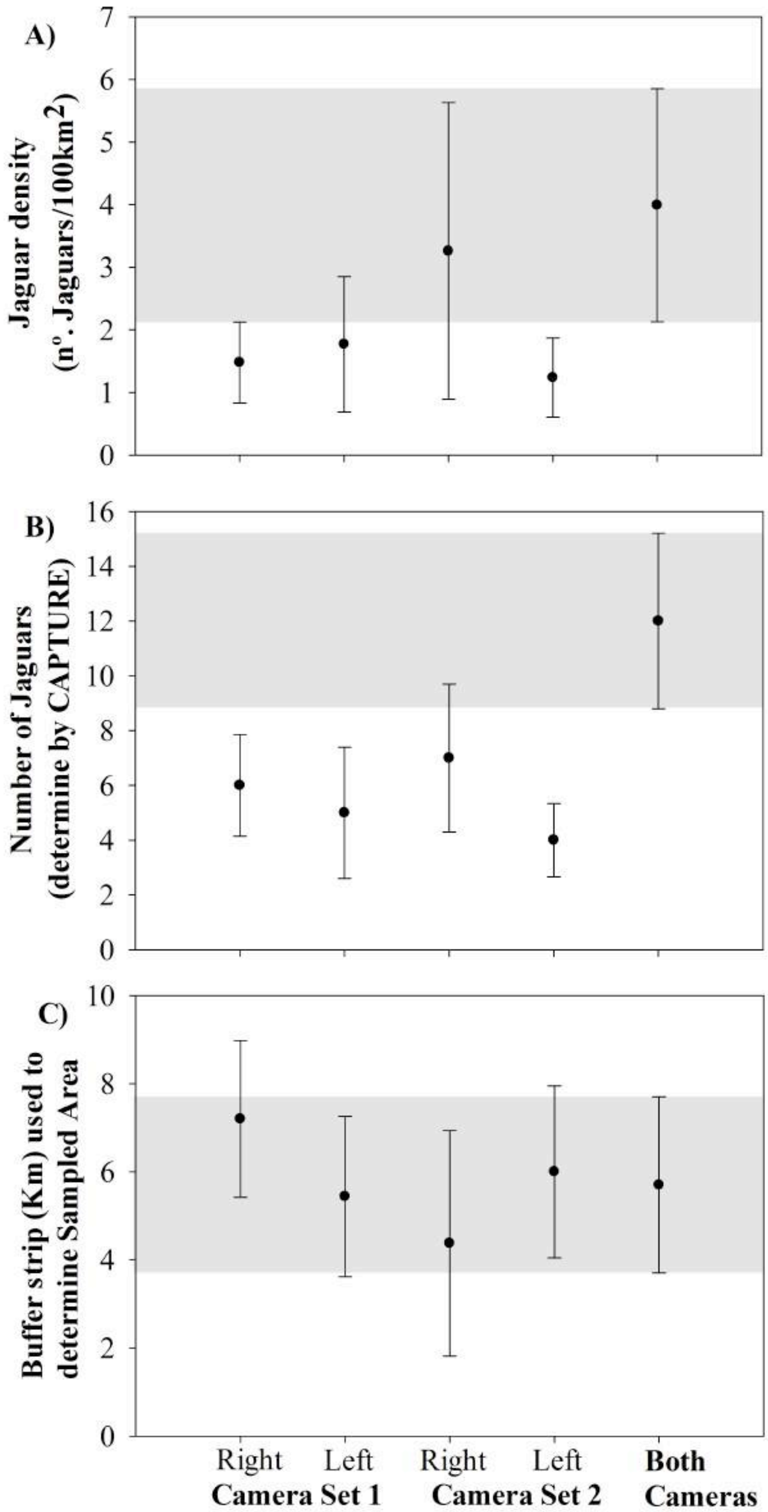

Figure 3.2- Different density estimates for jaguar (A), number of jaguars in the population (B) and buffer strip (C) estimated for determine sampled area (all with standard error) using one camera (Set 1 and Set 2) and two cameras (both cameras) per station in Santa Fé Ranch.

3.3.4- Selection of Roads versus Trails and Trap shyness

We were unable to obtain jaguar captures with the cameras placed on human-made trails (Fig. 3.3). In contrast there was positive selection for roads and jaguars seem to use different types of roads (low and high used) according to its availability (χ^2=83.03; $p<0.05$). The number of individual jaguars captured increased with time, with an exception at sampling occasion 4 that presented the lowest capture success (Fig. 3.3). The probability of detecting new individuals (those that were never recorded in previous sampling occasions) descended as the number of sampling events increased (Wald χ^2 = 5.10, P = 0.024, Fig. 3.3), with the majority of the individuals photographed at the end of the study corresponding to known jaguars (Fig. 3.3).

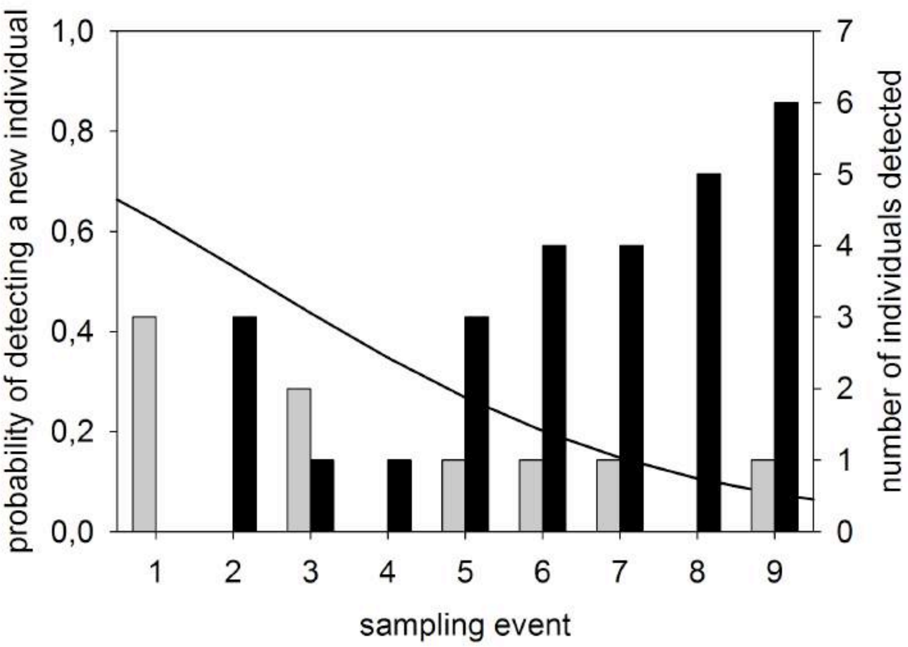

Figure 3.3- Probability of capturing new unknown individuals as a function of the sampling event (left Y axis) and the number of new (grey bar) and known (black bar) individual jaguars detected in each sampling event (right Y axis).

4- Discussion

Capture rates of jaguars and other species were significantly lower when using one camera per station than when using two cameras. These results are logic since by placing two cameras per station we increment the probability of photographing an animal passing along the station, and, as result, we increase our detection ability. On the other hand, the outcome from each camera individually did not diverge considerably, since both present the same technical characteristics and spatial position. An additional advantage of using two simultaneous cameras is that we have a higher capacity to individualize the animals because we have both flanks associated to the same individual. The relationship between capture rates and absolute density must be evaluated before further conclusions can be made, as occurs with all indices of relative abundance, and therefore it is not possible to attribute differences in capture rate to differences in abundance based only on presented data (Karanth et al., 2003, Balme et al., 2009).

Given that there is no information on the actual population size and the territorial behaviour in our study site, we cannot establish the exact density of jaguars in the area. But we can compare data on other jaguar densities estimates that applying camera trap using buffer area based on ½ MMDM. The density of 3.99 jaguars/100 km^2 (SE=±1.86) on the central Brazil forest area, was higher than the 0.2-2.22 jaguars/100km^2 observed in the Brazilian and Argentinean Atlantic Forest (Cullen et al., 2005, Paviolo et al., 2008), the 2.67 jaguars/100km^2 determine for the Caatinga (Silveira et al, in press.) and the 2.00 jaguars/100km^2 at Emas national Park, a Cerrado area (Silveira, 2004). Only populations from the Pantanal (10.3-11.7 jaguars/100km^2), tropical forest areas of Belize (7.48-8.80 jaguars/100km^2) and Costa Rica (6.98 jaguars/100km^2) present so far higher densities of jaguar (Silver et al., 2004; Soisalo and Cavalcanti, 2006; Salom-Pérez et al., 2007). Jaguar densities at the Bolivian Chaco (3.41-5.11 jaguars/100km^2) resemble the one obtained in this study (Maffei et al., 2004; Silver et al., 2004).

Comparing the estimates of jaguar density obtained with one or two cameras per station we can conclude that the differences are influenced by the estimates of population size, associated with the capture-recapture history. Those are related to the limitations that one camera per station poses in detecting and identifying an individual. Since there were no significant differences in MMDM between using one or two cameras, the sampled area did not influence the results assessed. The consistent differences between the density estimates obtained with one or two cameras per set are large enough to be relevant in monitoring programmes since they can affect our capacity to detect annual trends, especially when populations are present at low-densities (Balme et al., 2009).

In order to establish an efficient camera trapping protocol for jaguar population monitoring we must evaluate the two main components that affect the estimates:

population size and sampled area. Population size estimates are affected by our capacity to distinguish individuals and our effectiveness in registering with unbiased results that reflect the true population size (Karanth and Nicholds, 1998). The use of two cameras per station, allowing access to both flanks of individuals is essential, especially before we register most of the individuals of the population (Harmsen, 2006, Edgaonkar, 2008). Despite the reduced capture-recapture history obtained by using one camera per set, we obtained overall capture probabilities (p-hat) above the 0.1 threshold defined to obtain reliable results reliable (White et al., 1982). We did not detect trap shyness in jaguars, contrary to the one observed by Wegge et al. (2004) for tigers.

The absence of jaguar captures in recently opened trails highlights the importance of setting cameras in places, like roads and well-established trails to allow high capture probabilities for all individuals (Dillon and Kelly, 2007; Weckel et al., 2006). Camera spacing should be based on local minimum female home-range size (Karanth and Nicholds, 2002) and can play also a vital role in both population and sampled area estimates by affecting the capture probability required for all animals and contributing to bias in the relationship between trapping and effective sampled areas (Dillon and Kelly, 2008). According to Noss and Maffei (2005) the area covered by traps should include over four times the size of the average home range of the species in question. The lack of data on jaguar home range at our study area does not allow evaluating the effectiveness of our sampling design.

In conclusion, the use of one camera per station can be applicable in case of aiming for relative abundance estimates if samplings constrains (same area, best camera placement, equal effort) are respected. In all other cases, such as when we need actual accurate density estimates, the use of two cameras per station should be preferred, with stations located on roads and well-established open trails, evenly spaced according to data on jaguar home range size obtained at each study site and using a uniform sampling design and maintain the effort between samplings.

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References

Balme, G.A., Hunter, L.T.B. and Slotow, R. (2009). Evaluating methods for counting cryptic carnivores. Journal of Wildlife Management 73(3), 433-441.

Cullen Jr, L., Abreu, K.C., Sana, D., Nava, A.F.D., 2005. Jaguars as landscape detectives for the upper Paraná River corridor, Brazil, Natureza & Conservação 3, 147–161.

Dillon, A. and Kelly, M.J. (2007). Ocelot *Leopardus pardalis* in Belize: the impact of trap spacing and distance moved on density estimates. Oryx 41, 469–477.

Dillon, A. and Kelly, M.J. (2008). Ocelot home range, overlap and density: comparing radio telemetry with camera trapping. Journal of Zoology, London 275(4), 391-398.

Edgaonkar, A. (2008). Ecology of the Leopard (*Panthera pardus*) in Bori Wildlife Sanctuary and Sptura National Park, India. PhD Thesis. University of Florida, 135 pp.

Harmsen, B.J. (2006). The use of camera traps for estimating abundance and studying the ecology of jaguars (*Panthera onca*). PhD Thesis, University of Southampton. 275 pp.

Hernandez, F., Rollins, D. and Cantu, R. 1997. An evaluation of Trailmaster camera systems for identifying ground-nest predators. Wildlife Society Bulletin 25, 848–853.

Johnson, A., Vongkhamheng, C., Hedemark, M. and Saithongdam, T. (2006). Effects of human-carnivore conflict on tiger (*Panthera tigris*) and prey population in Lao PDR. Animal Conservation 9, 421-430.

Karanth, K.U. (1995). Estimating tiger *Panthera tigris* populations from camera-trap data using capture-recapture models. Biological Conservation, 71: 333-338.

Karanth, K.U and Nicholds, J.D. (1998). Estimating tiger (*Panthera tigris*) populations form camera-trap data using capture-recaptures. Ecology 79, 2852-2862.

Karanth, K.U. and Nicholds, J.D. (2002). Monitoring tigers and their prey. A Manual for researchers, managers and conservationists in Tropical Asia. Bangalore: Center for Widlife Studies, 193 pp.

Karanth, K.U., Nicholds, J.D., Seidensticker, J., Dinerstein, E., Smith, J.L.D., McDougal, C., Johnsingh, A.J.T., Chundawat, R.S. and Thapar, V. (2003). Science deficiency in conservation in practice: the monitoring of tiger populations in India. Animal Conservation 6, 141-146.

Karanth, K. U., Nichols, J. D., Kumar, N.S. and Hines, J.E. (2006). Assessing tiger population dynamics using photographic capture-recapture sampling. Ecology 87, 2925-2937.

Kawanishi, K. and Sunquist, M.E. (2004). Conservation status of tigers in a primary rainforest of Peninsular Malaysia. Biological Conservation 120, 329-344.

Kelly, M. (2008). Design, evaluate, refine: camera trap studies for elusive species. Animal Conservation 11, 182-184.

Kelly, M. J., Noss, A. J., Bitetti, M. S., Maffei, L.and Arispe, R. L. (2008). Estimating puma density from camera trapping across three study sites: Bolivia, Argentina, and Belize. Journal of Mammalogy 89(2), 408–418.

Linkie, M. Chapron, G., Martyr, D.J., Holden, J. and Leader-Williams, N. (2006). Assessing the viability of tiger sub-populations in a fragmented landscape. Journal of Applied Ecology 43, 576-586.

Maffei, L., Cuellar, E. and Noss, A. (2004). One thousand jaguars (*Panthera onca*) in Bolivian Chaco? Camera trapping in the Kaa-Iya National Park. Journal of Zoology, London 262(3), 295-304.

Maffei, L and Noss, A.J. (2008). How Small is too Small? Camera Trap Survey Areas and Density Estimates for Ocelots in the Bolivian Chaco. Biotropica 40(1), 71-75.

O´Brien, T., Kinnard, M.F. and Wibisono, H. T. (2003). Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. Animal Conservation 6, 131-139.

Otis, D.L., Burnham, K.P., White, G.C. and Anderson, D.R. (1978). Statistical inference from capture data on close population. Wildlife Monographs 62, 1-135.

Paviolo, A., De Angelo, C.D., Di Blanco, Y.E, Di Bitetti, M.S., 2008. Jaguar *Panthera onca* population decline in the Upper Paraná Atlantic Forest of Argentina and Brazil. Oryx 42, 554-561.

Rabinowitz, A.R. and Nottigham, B.G., Jr. (1986). Ecology and behaviour of the jaguar (*Panthera onca*) in Belize, Central America. Journal of Zoology, London 210, 149-159.

Rexstad,E. and Burnham, K.P. (1991). User's guide for interpretative program CAPTURE. Fort Collins, CO: Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University.

Rowcliffe, J.M. and Carbone, C. (2008). Surveys using camera traps: are we looking to a brighter future? Animal Conservation. 11, 185-186.

Salom-Pérez, R., Carrillo, E., Sáens, J.C. and Mora, M. (2007). Critical condition of the jaguar in Corcovado National Park, Costa Rica. Oryx 41(1), 51-56.

Sanderson, E. W., Redford, K. H., Chetkiewicz, C. B., Medellin, R., Rabinowitz, A., Robinson, J. and Taber, A. 2002. Planning to Save a Species: the Jaguar as a Model. Conservation Biology 16, 58–72.

Silveira, L. (2004). Ecologia comparada e conservação da onça-pintada (*Panthera onca*) e onça-parda (*Puma concolor*), no Cerrado e Pantanal. PhD thesis, University of Brazilia (Brazil). 240 pp.

Silveira, L., Jácomo, A. T. A. and Diniz-Filho, J. A. F., 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114, 351-355.

Silveira, L., Jácomo, A.T.A., Astete, S., Sollmann, R., Tôrres, N.M., Furtado, M.M., Marinho-Filho, J., in press. Jaguar density in the Caatinga of Northeastern Brazil. Oryx.

Silver, S.C. (2004). Assessing Jaguar abundance using remotely triggered cameras. Wildlife Conservation Socitey. 25 pp.

Silver, S.C., Ostro, L.E., Marsh, L.K., Maffei, L., Noss, A.J., Kelly, M.J., Wallace, R.B., Gómez, H. and Ayala, G. (2004). The use of camera traps for estimating jaguar *Panthera onca* abundance and density using capture/recapture analysis. Oryx 38 (2), 148-154.

Soisalo, M.K. and Cavalcanti, S.M.C. (2006). Estimating the density of a jaguar population in the Brazilian Pantanal using camera-traps and capture-recapture sampling in combination with GPS radio-telemetry. Biological Conservation 129, 487-496.

Stanley, T.R. and Burnham, K. P. (1999). A closure test for time-specific capture-recapture data. Environmental and Ecological Statistics 6, 197-209.

Tobler, M.W., Carrillo-Percastegui, S.E., Leite Pitman, R., Mares, R. and Powell, G. (2008). An evaluation of camera traps for inventorying large- and medium size terrestrial forest mammals. Animal Conservation 11, 169-178.

Trolle, M. (2003). Mammal survey in the southeastern Pantanal, Brazil, Biodiversity and Conservation 12, 823-836.

Trolle, M. and Kery, M. (2005). Camera-trap study of ocelot and other secretive mammals in the northern Pantanal. Mammalia 69, 409-416.

Wallace, R.B., Gomez, H., Ayala, G. and Espinoza, F. (2003). Camera trapping for jaguar (*Panthera onca*) in the Tuichi Valley, Bolivia. Mastozoological Neotropical 10, 5–11.

Weckel, M., Giuliana, W. and Silver, S. (2006). Jaguar (*Panthera onca*) feeding ecology: distribution of predator and prey through time and space. Journal of Zoology, London 270(1), 25-30.

Wegee, P., Pokheral, C.P. and Jnawali, S.R. (2004). Effects of trapping effort and trap shyness on estimates of tiger abundance from camera trap studies. Animal Conservation 7, 251-256.

White, G.C., Anderson, D.R., Burnham, K.P. and Otis, D.L. (1982). Capture-recapture and removal methods for sampling closed populations. Los Alamos, National Laboratory Publication LA-8787-NERP, Los Alamos, New Mexico, USA.

"Only after the last tree has been cut down. Only after the last river has been poisoned.
Only after the last fish has been caught.
Only then will you find that money cannot be eaten."

Cree Indian Prophecy

CHAPTER 4

The use of camera trapping to estimate puma (*Puma concolor*) density and influencing factors in a forest habitat of Central Brazil

The use of camera trapping to estimate puma (*Puma concolor*) density and influencing factors in a forest habitat of Central Brazil

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Abstract

We used remote triggered cameras to collect data about Puma (*Puma concolor*) in a tropical forested area where the status of the species is poorly known. We used data from five sampling campaigns that cover 3 consecutive years (2005 to 2007) and 2 seasons (rainy and dry) obtained at a state protected park and a private forest reserve to evaluate the factors that influence puma presence and relative abundance. We estimated puma numbers and density for the 2007 sampling data by developing a standardized individual identification method. The individual identification was based on two types of physical parameters: 1) time Stable Parameters-SP (physical features that do not change with time) and 2) time Variable Parameters-VP (marks that could change with time such as scars and botflies marks). A capture-recapture history was established post identification and analyzed using capture-mark-recapture closed population models. Results indicated that presence and abundance were influenced by the place where camera was set (preferring roads over trails) and year of sampling. Presence was also associated with the richness of species and, on the other hand, puma and jaguar abundance appear to be correlated. Identifications enabled us to generate 8 VP histories for each flank, which corresponded to 8 identified individuals. We estimated the sampled population at 9 pumas (SE = 1.03, 95% CI = 8-10 individuals) corresponding to a density of 3.40 pumas/ 100 km^2. Information collected using camera-trap can effectively be used to assess puma population size in tropical forests. Our results support the critical importance of private forest reserves for conservation, since habitat continues to disappear and South American felines are becoming more vulnerable.

Key words: Amazon basin, camera-trapping, density estimation, individual identification, CAPTURE software, *Puma concolor*, private reserve

4.1- Introduction

Although pumas *Puma concolor* are widespread through Central and South America, their status remains poorly known over most of their range south of the United States (Nowell and Jackson, 1996; Sunquist and Sunquist 2002). Being a more adaptable species than the other large cat of the Americas, the jaguar *Panthera onca*, pumas are more widely distributed over a larger range of altitudes, ranging from sea level to 5800 meters (Redford and Heisenberg, 1992). Habitats occupied by pumas are diverse and include desert, rainforest, mountain forest and arid scrub (Eisenberg, 1989; Laundré and Loxterman, 2007). Despite the capacity of the species to adapt to different environments and its generalist habits as a predator (Pacheco et al., 2004) it is likely that numbers of pumas have decreased in recent years because of declines in prey, habitat loss and fragmentation (Kelly et al., 2008).

There is considerable lack of information on puma density, particularly in dense tropical forest habitats of Central or South America (Kelly et al., 2008) and most density estimates come from radio-tracking studies, which mostly are based on small sample sizes. Although classified as Least Concern (IUCN et al., 2008), the on-going habitat destruction, which it is reaching high levels in the neotropics, may be a threat to the survival of the species (Logan and Sweanor, 2001). Thus, the evaluation of the status of populations locally and regionally and the development of conservation action plans based on these evaluations is crucial for puma conservation (Nowell and Jackson, 1996; Kelly et al., 2008).

Recently, camera trapping has been used to study carnivore populations to address a variety of questions (Carbone et al., 2001; Trolle and Kery, 2005). This method is particularly useful for species that are individually identifiable, as with appropriate mark-recapture experimental design and analysis, it allows the estimation of abundance and population density, as well as providing information on ranging behavior, activity patterns, and dispersal/migration (Karanth and Nichols, 1998; Cutler and Swann, 1999; Silveira, et al., 2003).

In this context, Kelly et al. (2008) recently assessed the reliability with which pumas can be identified by photo-trapping by their individual marks based on double-blind observer identifications, created capture histories based on the identifications made by each investigator, and used capture-recapture models (Rexstad and Burnham, 1991) to estimate the abundance of pumas across study sites and by different investigators.

In this study we estimate the abundance and density of pumas in central Brazil by adapting the approach used by Kelly et al. (2008) using remote triggered cameras. Additionally, we use data from several camera-trapping campaigns to determine descriptive variables than can explain presence and relative abundance at a local level. Finally, we also give information on puma photographic capture success, activity pattern and trail use.

4.2- Material and Methods

4.2.1- Study area

The study was carried out in the middle Araguaia river basin in two areas at opposite sides of the river: the Cantão State Park (CS-Park) and the Santa Fé Ranch (SF-Ranch) (Fig 4.1). CS-Park (09º36'S, 50º03'W) is an 89.000 ha conservation unit situated in the transitional area between the Amazon and the *Cerrado* biomes. Water abundance suffers a dramatic cyclical change due to extent large network of rivers, canals and lakes. With an annual average precipitation of 1,710 mm/year and a difference of more than 4 meter of river level between seasons (data from SF-Ranch), flooding conditions influence available resources (food and shelter) for fauna in a spatial and temporal dimension. Vegetation suffers from partial flooding during the wet season and is mainly represented by secondary growth tropical rainforest with some small areas being occupied by grasslands.

SF-Ranch (09°34'S, 50°21'W) is a 65.000 ha beef cattle ranch in the southeast Pará State, margining the Araguaia River. Around 65 % of the ranch presents a continuous semi-deciduous seasonal tropical forest patch that extrapolates the farm boundaries, whether the other 35% are occupied almost entirely by pasture.

The area is located in the arc of deforestation, a transitional area between the Savannah (*Cerrado*) and Amazon ecosystems, where an increased pressure from human occupation results in a mosaic landscape of agricultural farms and forest fragments of various sizes along the southern frontier of the Amazon basin (Morton et al., 2006).

Figure 4.1 – Study area showing Santa Fé Ranch and Cantão State Park were puma census were done.

4.2.2- Field methods

The research is part of long-term jaguar and puma monitoring program for the medium Araguaia River and consequently camera trap design was structure to evaluate population density of these carnivores and their prey species.

The use of camera traps to detect elusive felines in South America forests has proved to be highly efficient (Wallace et al., 2003; Silver et al., 2004; Kelly et al., 2008). The technique has the advantage of being cost-effective by providing positive species identification and detecting cryptic animals with inconspicuous habits with low disturbance effect (Zielinski et al., 1995).

4.2.3- Camera Trapping

We conducted five camera trap surveys, between July 2005 to November 2007, during both the dry (three samplings) and wet seasons (two samplings). A variable number of stations (from 10 to 22) were set throughout the area separated between 1 and 3 km (Rabinowitz and Nottigham, 1986; Karanth and Nicholds, 2002; Silver et al, 2004). Every station consisted of one passive infrared camera set on dirt roads or trails (animal or human made), at approximately 50-70 cm from the ground, except during the 2007 dry season sampling at SFR when there were set two cameras per station (Silver, 2004). During the study two different camera types were used: the Camtrakker (Cam Trakker, Watkinsville, USA) and the C1-BU (Vibrashine Inc., Taylorsville, MS 3968, USA). Each camera was programmed to take photographs 24h/day with a 5-min interval between photos. All stations were checked on a regular basis (5-20 days) throughout the all surveys for film and battery change.

Individual photographs were analysed in order to collect information concerning species identification, number of individuals, sex (male/female), age (adult/sub-adult/juvenil/cub), date and hour. Each photo was considered has independent event only if meet one of three criteria's: consecutive photographs of different individuals of the same or different species; consecutive photographs of individuals of same species taken more than 1 hour apart; non-consecutive photos of individuals of the same species (O'Brien et al., 2003).

For each camera location the relative abundance index (RAI) was determined for all species by dividing the number of independent captures multiplied by the average group number for the species and then divided by effort (trap-nights) times 100 (O'Brien *et al.*, 2003; Kawanishi and Sunquist, 2004). RAI was multiplied by the mean weight for the species collected from bibliography (Sick, 1997; IUCN et al., 2008) in order to establish a relative biomass abundance index (BAI) for each camera location.

4.2.4- Puma presence and relative abundance models

Each trap location was characterized according to several numerical and categorical variables (Table 4.1). Due to the relative homogeneity within the two areas (SFR/CSP) at a macro scale level, no vegetation variable was evaluated. We used two dependent variables: puma presence/absence and number of photos at each location (puma relative abundance). We designed the models after five general hypotheses: 1) Puma photos varied in time, space and sampled area; 2) Puma mainly requires prey availability (Laundré et al., 2007); 3) Human disturbance factors are the main determinants of presence and abundance (Haines, 2006); 4) Jaguar presence can influence pumas presence/abundance (Scognamillo et al., 2003; Moreno et al., 2006); and 5) puma is affected by a combination of both anthropogenic and environmental factors (Haines, 2006). Since the effort in each camera location was not constant we use the number of days of camera activity as a predictor in all models to control for its influence from the analysis. Fitted models were compared using the Aikaike Information Criterion (AIC) and the model with lowest AIC was selected (Akaike, 1973). Variables that presented strong correlation ($r > 0.7$) were not included in the same model, selecting the one that presented the lowest AIC in a single variable model. The generalised linear mixed models (with station code included as a random variable) were performed using the procedure GLIMMIX (SAS Inst. Inc., Cary, NC) and R v.8.2 free statistical software and the Lme4 package for mixed models (Anon. 2005; Bates and Sarkar, 2006).

Table 4.1 – Variables used in models evaluation from different hypotheses for puma' presence and abundance.

		Model Hypotheses			
Variable Name	Description	Sampling	Food	Human Disturbance	Jaguar
Area	SRF/CSP	X		X	
Year	2005/2006/2007	X			
Place	Road/Trail	X			
Distance to Road	Minimum distance to road (meters)			X	
Distance to Pasture	Minimum distance to pasture (meters)		X	X	
Distance to River	Minimum distance to river (meters)			X	
Distance to closest water source	Minimum distance to closest water source (meters)		X		
Index of Prey Biomass	BAI index of prey species present		X		
Diversity of Prey species	Number of prey species present		X		
Diversity of Species	Number of species present		X		
Jaguar presence	Presence/absence of jaguar photos				X
Jaguar abundance	Number of jaguar photos				X

4.2.5- Individual identification, density estimate and activity pattern

Data collected from the two cameras per station system set between September and November 2007 in SFR was used to determine density of puma, following a well established camera trapping protocol and capture-recapture analysis (Karanth and Nichols, 1998; Moruzzi et al., 2002; Jackson et al., 2006; Kelly et al., 2008; Rowcliffe and Carbone, 2008). A total of 21 sampling stations were set on dirt roads and human made trails throughout the 80-day survey period.

In order to determine density, camera trap sampling was guided by two critical premises (Karanth and Nichols 1998): 1) The population of the target species should be considered closed (no gains or losses during sampling); 2) All animals inhabiting the study area should have a probability of being detected. The first premise is achieved by an adequate sampling period, which according to similar research on other large cat species (e.g. tiger and jaguar), should be no longer than two to three months (Karanth and Nicholds, 1998, Silver *et al.*, 2004). The second premise is accomplished by placing the cameras at a distance of no more than the diameter of a circle whose area is given by the smallest home-range described for the species in the study area. This is to ensure that there are no holes in the sampling area, and, consequently, that every puma has a non-zero probability of being photographed during sampling (Karanth, 1995). Due to the lack of information on the home range of pumas in the area we used data from similar studies and for similar species (Silveira, 2004; Kelly et al., 2008).

Using the date and time of each photograph we describe the pattern of activity of pumas in the rainforest. Camera stations were set up on two types of dirt roads, high-use (roads used weekly by people) and low-use (roads used no more than once per month) and 4 human made trails established 2 months before sampling. We used χ^2 test to determine if pumas used particular types of trail/roads more often than expected and Ivlev Selectivity index (SI) to evaluate pumas selectivity towards different types of trail/road: $SI = (r_i - p_i)/(r_i + p_i)$ where r_i = proportion of photos in trail/road type i, and p_i = proportion of trail/road type i availability. Values of Ivlev's index (1) range from -1 (complete avoidance) to +1 (exclusive selection) (Manly et al., 2002).

The individual identification of pumas was based on two types of physical parameters: 1) time Stable Parameters (SP) and 2) time Variable Parameters (VP) (Figure 4.2). SP were classified as physical features that do not change along time (e.g. kinked tail,

tail tip coloration, undercoat spot patterns and coloration on the underside of legs (Kelly et al., 2008). VP consisted of marks that could vary with time such as scars and botflies marks.

Each photograph was examined for subject orientation, resolution and framing to detect unique markings useful for identification based on the adaptation of the guidelines from Jackson et al. (2006):

1. An initial capture was defined as a photograph that could not be positively matched with a previously photographed puma;
2. A recapture was only considered a photograph that could be positively matched to a previously identified animal;
3. Different body areas used for identification were classified as primary or secondary features. A primary feature was designated for each photograph and was identified as the most distinct feature useful for identification. All other useful marks were classified as secondary features;
4. For determining an initial capture or recapture, a positive identification was made by comparing the primary feature and at least 2 secondary features.

Photographs were ordered chronologically and for each flank we mapped all SP in order to do a preliminary arrangement of individuals. Then we identified all VP for the first photograph of each preliminary identified individual and then we continued with this procedure for the following photographs, adding new VP features as they appeared (see the example of Figure 4.2). This allowed us to generate SP and VP charts that were used for the final individual identification (see the example of Figure 4.2).

We estimated puma abundance using the CAPTURE software (Rexstad and Burnham 1991), following the procedures described by Otis *et al.* (1978), White *et al.* (1982), and Karanth and Nichols (1998). This program tests several models that differ in their assumed sources of variation in capture probability. The null model (M_0), which is the simplest, assumes no variation. More complex models are the heterogeneity model (M_h) (for this, capture probability differs between individuals due to age, sex, ranging patterns, etc.); the time variation model (M_t) (capture probabilities are influenced by time); and the behavior model (M_b), which results from different probabilities of capture and recaptures. The software identifies the model that best fits the data in question and then generates capture statistics for all adequately fitted models, along with a statistical evaluation of the population closure assumption (Stanley and Burnham, 1999). We considered 7-days of consecutive trapping as a single sampling occasion and created a capture-recapture history for each puma identified within the survey.

To determine the size of the sampled area, the mean of the maximum distance moved between cameras was calculated for each puma captured more than once and half this distance was used (½ MMDM) as the buffer radius around each camera station (Silver *et al.*, 2004). Number of individuals determined by CAPTURE was divided by the total surveyed area in order to obtain the puma density.

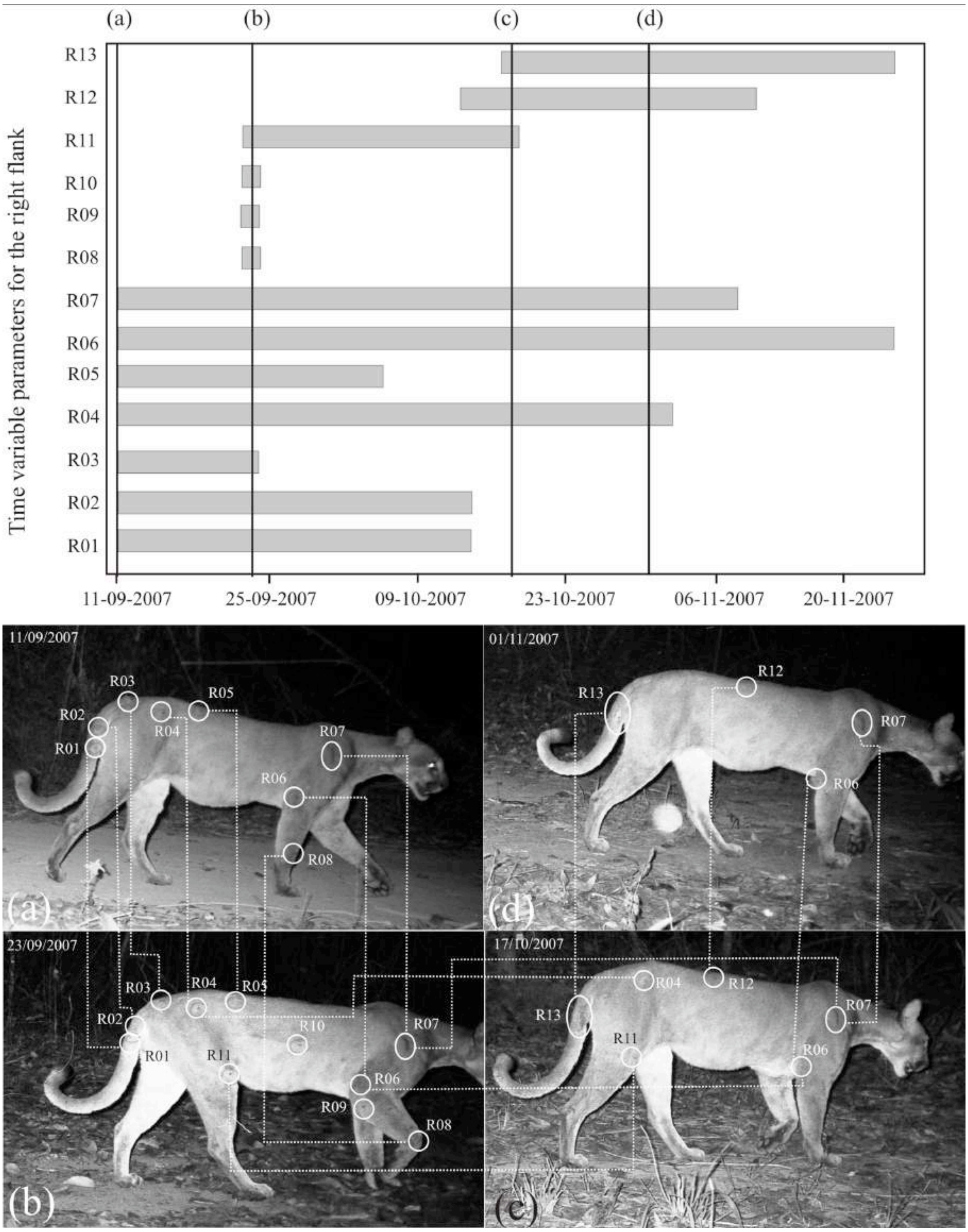

Figure 4.2 – Example of a group of 19 Variable parameters (VP) history chart used to identify an adult puma. The bars represent the persistence of VP between photographs (a), (b), (c) and (d) below. The images show the established time variable parameters (VP) and their persistence between dates.

4.3- Results

4.3.1- Capture success

A total of 7929 camera-nights recorded 101 puma captures, representing an average capture success (RAI) of 1.27 captures/100 trap-nights, which equals 1 puma capture every 79 nights of trapping. Pumas were photographed in 24.7 % of all the trapping stations. On average, we obtained 0.79 (SE = 0.18, range 0 - 12) captures per trap.

The values of average RAI obtained at the CSP were 0.06 (SE = 0.06) for 2005 and 0.13 (SE = 0.09) for 2006 dry seasons (Table 4.2), while in SFR the average RAI was considerable higher (*Mann-Whitney U-Test* W = 331, $P = 0.013$) ranging from 0.41 (SE = 0.23) and 3.63 (SE = 0.94). There was no significant difference in average RAI within samplings at SFR, except when comparing 2006 and 2007 rainy season campaign (*Mann-Whitney U-Test* W= 38, $P = 0.017$). Globally less than 10% in CSP and over 20% at SFR of camera stations detected puma presence (Table 4.2).

The occurrence of other 45 medium sized-mammal and bird species was detected. It was possible to determine Jaguar RAI, Prey BAI and Richness (number of species per camera station) that were incorporated in the following analyses.

4.3.2- Puma presence and relative abundance

The analysis of puma presence and number of photos per station shows that the a priori hypothesis best adjusted to data is that the species is affected by a combination of both anthropogenic and environmental factors,. The most parsimonious model for puma presence incorporates as predictors the number of days, year, place and richness of species with a 56% probability of selection (Table 4.3). The same variables adding jaguar presence and its interaction with species richness are included in the second best model that presents a selection probability of 44%. On the other hand, the analysis of relative abundance revealed days, year and jaguar abundance as the predictors of the best model with a 71% selection probability. The second best model for puma abundance presented a probability of selection of 28% and included the same variables as the former plus species richness.

Puma presence was strongly correlated with place factor ($P < 0.05$), showing that it was much more likely detecting the species in cameras set on roads that in trails (Table 4.4). The year of sampling was positive and highly correlated ($P < 0.05$) suggesting an increase of puma numbers along the study. A significant correlation was revealed between jaguar and puma relative abundance ($r = 0.7212$; $P < 0.001$).

Table 4.2- Results of five camera trapping campaigns executed in the Cantão State Park (CSP) and Santa Fé Ranch (SFR) in Centra Brazil (Nº Stations =number of camera trap stations active throughout the sampling; Total Effort= total number of days camera stations were functional; Mean Days= average number of days cameras were active/sampling campaign; Mean RAI Puma= average number of photos of puma/number of days camera was active plus 100; Min-Max RAI= minimum and maximum number of photos of puma/number of days camera was active plus 100; %Stations with detection=% of camera stations that presented at least one puma' photo.

	Cantão State Park			Santa Fé Ranch				
	2005	2006		2005	2006		2007	
	Dry	Rain	Dry	Dry	Rain	Dry	Rain	Dry
Nº Stations	21	10	22	12	14	17	11	21
Total Effort (Camera-days)	1390	626	1167	764	662	1114	525	1681
Mean Days	66	63	53	64	47	66	48	80
Mean RAI Puma (SE)	0.059 (±0.059)	0	0.130 (±0.09)	0.413 (±0.231)	0.837 (±0.459)	0.985 (±0.368)	3.625 (±0.939)	3.464 (±1.263)
Min-Max RAI	0 - 1.235	0 - 0	0 - 1.429	0 - 2.410	0 - 4.545	0 - 5.405	0 - 7.500	0 - 21.818
%Stations with detection	4.8	0	9.1	25.0	21.4	41.2	63.6	52.4

Table 4.3-Summary of models for predicting puma presence and abundance in central Brazil according to five different hypotheses of factors potentially affecting it.

	Model	AIC	Deviance	ΔAIC	wAIC
	Puma presence				
1A	*Null Model*	152.2	148.2	70.87	0.00
	Sampling Variables				
1B	Days+Place*** +Season+Year***	100.7	88.67	19.37	0.00
	Food Variables				
1C	Days+Diversidade***+ Dist_Past	108.4	98.37	27.07	0.00
	Human disturbance				
1D	Days+Area+Dist_road*	122.3	112.3	40.97	0.00
	Jaguar				
1E	Day+Jaguar abundance***	118.9	110.9	37.57	0.00
	Combining Variables				
1F	Days+Place***+Year**+Diversity***	81.78	69.78	0.45	0.44
1G	Days+Place***+Year**+Diversity x Jaguar presence	81.33	65.33	0.00	0.56
	Puma Abundance				
2A	*Null Model*	72.28	68.28	36.43	0.00
	Sampling Variables				
2B	Days**+Year***+ Place*	43.13	33.13	7.28	0.00
	Food Variables				
2C	Days+Diversidade**	67.53	59.53	31.68	0.00
	Human disturbance				
2D	Days+Area+Dist_river+Dist_Road	69.74	57.74	33.89	0.02
	Jaguar				
2E	Days+Jaguar number***	43.57	35.57	7.72	0.02
	Combining Variables				
2F	Days+Year***+Jaguar abundance***+Diversity	37.81	25.81	1.89	0.28
2G	Days+Year***+Jaguar abundance***	35.85	25.92	0.00	0.71

Table 4.4- Estimated coefficients (± standard error) for the variables of the two best models for puma presence and abundance in central Brazil (* significant at 0.05; ** significant at 0.01; *** significant at 0.001).

Variables	Puma presence		Puma abundance	
	Model 1F	*Model 1G*	*Model 2F*	*Model 2G*
Intercept	-0.0027±0.001**	-0.0029±0.0011**	-0.0011±0.0414**	-0.0012±0.0404**
Days	0.0074±0.0171	0.0009±0.0176	0.0065±0.0078	0.0075±0.0173
Year	1.33±0.5096**	1.469±0.5558**	0.5597±0.2062**	0.5778±0.2011**
Place	-4.462±1.222***	-3.490±1.283**		
Diversity	0.4498±0.1208***	0.2656±0.1375	0.1068±0.03236	
Jaguar Presence		-1.998±1.421		
Jaguar Presence*Diversity		0.5513±0.2985		
Jaguar Abundance			0.1145±0.0325***	0.1462±0.0322***

4.3.3- Identification of puma photographs

Following the patterns in SP and VP we were able to identify 8 individuals. On average each animal was recaptured 2.17 times (SE = 2.17; range 0 - 19). From the 8 captured animals, 5 were positively identified as males, 2 as females, and 1 of unknown gender (sex ratio 1:2.5). We documented one female with a juvenile confirming reproduction in the study area.

Cameras were set to photograph pumas from lateral view in order to detect the most diagnostic features. Consequently, most pumas were photographed with at least 75% of the torso and tail visible (75.6 %). In 49.4% of the samples at least 3 members were photographed and 25.0% of the pumas were sideways to the camera (approximately 90º). Some of the photos had poor quality as a result of lighting, angle, or capture of only part of an animal in the photograph, but represent a small percentage of the total number of photos (12.8%).

For each photograph we identified, on average, 1.12 SP (SE = 0.07; n = 75) and 4.36 VP (SE = 0.66; n = 51) for the right flank and 3.64 VP (SE= 1.66; n = 24) for the left flank. These identifications enabled us to generate 8 VP histories for each flank, which corresponded to the 8 identified individuals (see the example of Figure 4.2). For the first photograph of each VP history we identified, on average, 5.33 (SE = 0.31; n = 8) parameters. From these, on the last VP history photograph, on average, only 0.33 (SE= 1.60; n = 8) VP persisted. If we considered the persistence of the VP from the previous photograph this value averaged 3.73 (SE = 1.21; n = 66), clearly sufficient for an adequate identification using the criteria given by Jackson et al. (2006).

4.3.4- Capture probabilities, population size and density

The heterogeneity model (M_h) was the most suitable model for the data and since it incorporates individual heterogeneity in capture probability, it can be considered an adequate reflection of the biological reality (Karanth and Nichols, 1998). The capture history did not break of the closed population assumption (z = -0.224; P = 0.121) and estimated the population at 9 individuals (SE = 0.87, 95% CI = 8 - 10 individuals) with a capture probability of 0.36.

The MMDM was determined by analyzing recapture data from 6 individuals and was estimated at 8.4 km (0 - 16.0), resulting in a buffer-strip width of 4.2 km (½

MMDM), which corresponded to an effective sampled area of 264.7 km^2. Considering this value we obtained a density estimate of 3.4 (SE = 2.04) individuals/100 km^2.

4.3.5- Puma activity and trail use

Pumas showed a nocturnal activity pattern with peaks of activity at crepuscular hours and between 00:00-02:00 (Figure 4.3). There were significant differences between night and day activity (χ^2 =14.02; n= 62; $P < 0.001$). Pumas did not use different types of road and trails as expected by their relative availability (χ^2 = 97.89; n= 62; $P < 0.001$). Ivlev's Index indicated that pumas used roads (especially low use ones) more than expected from their availability and exhibited avoidance of human made trails (Figure 4.4).

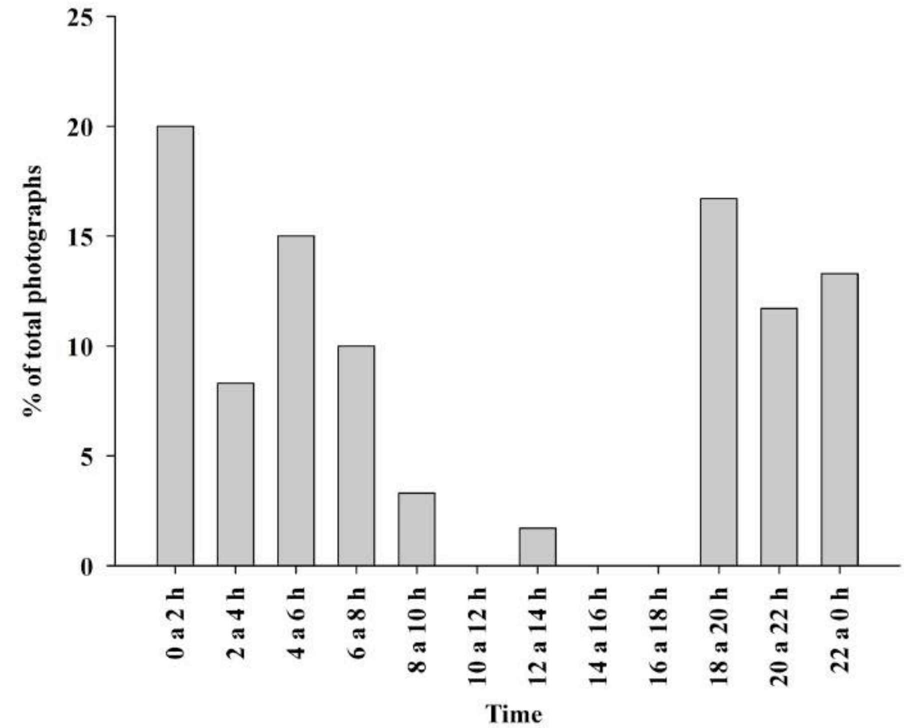

Figure 4.3- Daily activity patterns of puma form camera trapping history at Cantão State Park region (Central Brasil).

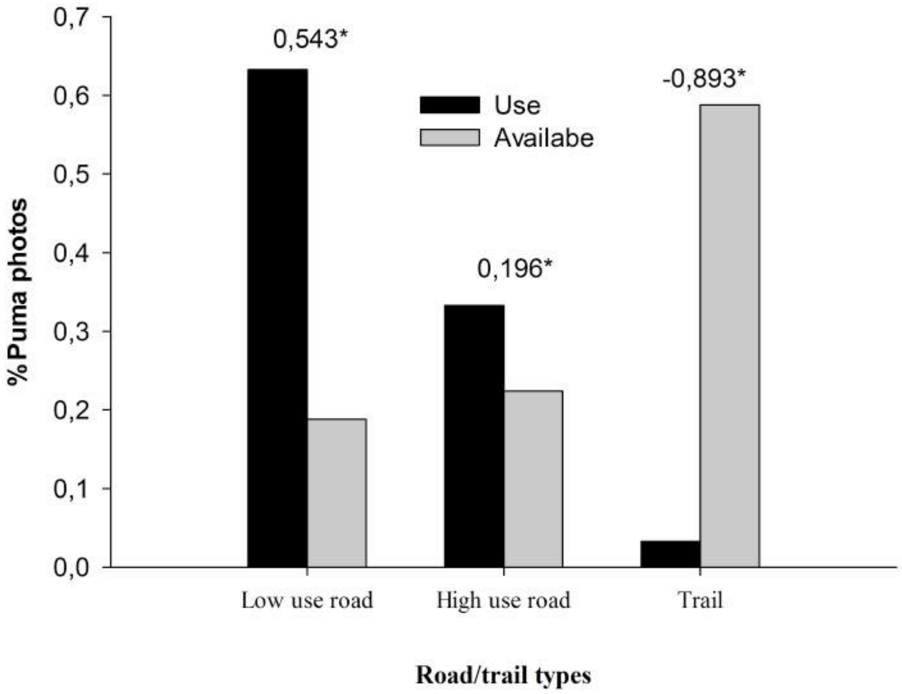

Figure 4.4- Percentage use of trail and road types by the puma in a forest area in Central Brazil (*Ivlev' Index of Selectivity).

4.3- Discussion

As wide ranging predators with low population densities, pumas are among the most difficult terrestrial mammals to census and no reliable enumeration technique exists that does not require extraordinarily intensive field efforts (Lindzey 1987; Smallwood and Fitzhugh 1995). Usual methods employed to estimate puma population size (e.g. capture combined with radiotelemetry, scent-stations, track-counts and hunter kills) are time consuming and/or expensive (Choate et al., 2006).

The results obtained in our study emphasise that photographic capture-recapture sampling a useful tools for estimating puma population size (Kelly et al., 2008). Our method for individual identification, based on fixed SP and VP time variation, proved to be practical and effective, which allowed us the individual identification of photographs than otherwise could be wrongly identified. Although SP could not be used for all identifications, these can also be useful for a preliminary assessment and for clarifying doubtful situations. So, in further studies we advise the use of a camera setup scenario based on 2 cameras placed on each side of potential movement paths and oriented at 45º in relation to it, to obtain good-quality side-profile photographs that can be use to generate

VP history charts. Although individual identification of pumas is more difficult than that of spotted or striped species (Karanth and Nichols, 1998; Heilbrun et al., 2003; Jackson et al., 2006), we proved that the use of this method is practical and time efficient. Although the approach developed by Kelly et al. (2008) of conducting a blind identification test of the puma photographs with the participation of three investigators reached an average agreement on identification between pairs of investigators of nearly 80.0% and 3-way agreement of 72.9%, we believe this process is much more time consuming and consistent results can also be achieved with our approach. Using this protocol we expect that data collected with camera trapping targeting other species (e.g. jaguar) can also be analyzed in order to contribute information about puma density across its southern distribution range.

Data revealed differences in capture probability between individuals. The presence of individual heterogeneity is obvious, since 2 of the pumas accounted for 48% of all captures. A photographic sex ratio skewed towards males has been observed for pumas (Kelly et al., 2008), tigers (*Panthera tigris*) (Karanth and Nichols, 1998; O´Brien et al., 2003) and jaguars (Silver et al., 2004), and given that the probability of identifying an individual as a male is higher than as a female (most of the females would be included in the group of non sexed individuals), the biological relevance of these sex ratios is low. Nevertheless information about territorial behavior and home range size for both sexes is not available and further analysis cannot be made.

Camera placement must be taken into account to reduce potential sources of bias in estimating density. The fact that variable Place (Road/Trail) appear in both best models concerning puma presence together with the fact that pumas avoid trails and selected low- and high-use roads emphasizes the importance of camera placement in order to maximize capture probability (Karanth and Nicholds, 1998). The use of existing roads or to establish a permanent large trail system seems essential when establishing a camera survey design (Dillon and Kelly, 2007).

Recent studies have shown that trap spacing (Dillon and Kelly, 2007), small survey area (Maffei and Noss, 2008) and the generalized use of ½ MMDM collected from camera traps (Soisalo and Cavalcanti, 2006) can overestimate density by underestimating effective sampled area. Information concerning camera distance and total sampled area should be based on the home range of the target species at the local study site, data that was not available for the present study and so further researches should approach insights that can contribute to a reduced bias camera trapping protocol.

Pumas presented a typical nocturnal behavior like in North America (Waid, 1990; McCain, 2008; Sweanor et al., 2008), Peru (Emmons, 1987), Venezuela (Scognamillo et al., 2003) and Brazil (Silveira, 2004). Our density estimates (3.40 pumas/100 km^2) confirm the tendency of significant variation of this species density along its geographic range. For the North American areas, density is usually much lower with less than one individual/100 km^2 (Hemker et al., 1984; Lindzey et al., 1994). In South America Kelly et al. (2008) reported densities per 100 km^2 of 5.13 to 8.01 for Bolivia, 0.50 to 0.81 for Argentina and 2.35 to 4.91 for Belize. Our results are closer to the ones obtained for Belize, which can be explained by similarities at habitat level (tropical forest with low understory cover) or prey availability (Kelly et al., 2008).

An increase of puma RAI throughout the years of sampling was observed together with positive influence of the year of sampling in detection and occurrence of this species in the area. Also puma seem to be present and more abundant in cameras with higher richness of species but the interaction of this variable with jaguar presence is not clear. There is no sufficient data to associate both facts but this felids species do coexist with segregation occurring at prey and habitat level (Scognamillo et al., 2003). At the deforestation arc, were the study area is integrated, the existence of habitat fragmentation, prey reduction and direct persecution of the jaguar may be altering jaguar and puma coexistence but further insights should be based on more research (Peres and Zimmerman, 2000; Haines, 2006).

The Santa Fé Ranch private forest reserve presented a higher puma relative density (RAI) in contrast to the neighboring public conservation unit, Cantão Sate Park (Table 4.2). This fact highlights the importance of private land together with protected areas in the creation of effective conservation networks for carnivores in general and pumas in particular (Beier, 1993; Heines et al., 2006; Kautz et al., 2006; Wilson et al., 2006). This issue is of exceptional importance since habitat and prey continue to disappear, and persecution due to cattle predation increases the vulnerability of large felines in South America (Rabinowitz, 1986; Nowell and Jackson, 1996; Silveira and Jacomo, 2002; Scognamillo et al., 2003).

This study provides the first puma density estimate in the Amazon. Considering that hardly any density estimates are available from forested environments in Central and South America (apart from Kelly et al., 2008) this gap impairs further comparisons. Therefore, we recommend further studies using reliable standardized protocols in the neotropics.

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References

Akaike, H., 1973. Information theory as an extension of the Maximum likelihood principle. In: Petrov, B.N., Csaki, F. (Eds.), Second International Symposium on InformationTheory. Akademiai Kiado, Budapest, Hungary, pp. 267–281.

Bates, D., Sarkar, D., 2006. Lme4: linear mixed-effect models using S4 classes, <http://www.R-project.org>.

Beier, P. (1993). Dertermining Minimum Habitat Areas and Habitat Corridors for Cougars. Conservation Biology 7(1), 94-108.

Carbone, C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J. R., Griffiths, M., Holden, J., Kawanishi, K., Kinnaird, M., Laidlaw, R., Lynam, A., Macdonald, D. W., Martyr, D., McDougal, C., Nath, L., O'Brien, T., Seidensticker, J., Smith, D. J. L., Sunquist, M., Tilson, R. and Shahruddin W. N. (2001). The use of photographic rates to estimate densities of tigers and other cryptic mammals. Animal Conservation 4 (1), 75-79.

Choate, D.M., Wolfe, M.L. and Stoner, D.C. (2006). Evaluation of Cougar Populations Estimators in Utah. Wildlife Society Bulletin 34(3), 782-799.

Cutler, T. L. and Swann, D. E. (1999). Using remote photography in wildlife ecology: a review. Wildlife Society Bulletin 23, 571–581.

Dillon, A. and Kelly, M.J. (2007). Ocelot *Leopardus pardalis* in Belize: the impact of trap spacing and distance moved on density estimates. Oryx 41(4), 1-9.

Eisenberg, J.F. (1989). Mammals of the Neotropics Vol I. University of Chicago Press, Chicago.

Emmons, L. H. (1987). Comparative feeding ecology of felids in a neotropical rainforest. Behavioural Ecology and Sociobiology 20, 271-283.

Haines, A.M. (2006). Is there competition between sympatric jaguar *Panthera onca* and puma *Puma concolor*? Acta Zoologica Sinica 52(6),1142-1147.

Heilbrun, R. D., Silvy, N. J., Tewes, M. E. and Peterson, M. J. (2003). Using automatically triggered cameras to individually identify bobcats. Wildlife Society Bulletin 31, 748-755.

Heines, A. M., Janecka, J. E., Tewes, M. E., Grassman Jr, L. I. and Morton, P. (2006). The importance of private lands for ocelot *Leopardus pardalis* conservation in the United States. Oryx 4(1), 90-94.

Hemker, T.P., Lindzey, F.G. and Ackerman, B.B. (1984). Population characteristics and movement pattern of cougars in southern Utah. Journal of Wildlife Management 48, 1275–1284.

IUCN, Conservation International, Arizona State University, Texas AandM University, University of Rome, University of Virginia, Zoological Society London. 2008. An Analysis of Mammals on the 2008 IUCN Red List <www.iucnredlist.org/mammals>. Downloaded on 12 December 2008.

Jackson, R. M., Roe, J., Wangchuk, R. and Hunter, D. (2006). Surveying snow leopard populations with emphasis on camera trapping: a handbook. Snow leopard conservancy, Sonoma, California, USA.

Karanth, K.U. (1995). Estimating Tiger (*Panthera tigris*) populations from Camera-trap data using Capture-Recapture models. Biological Conservation 71,333-338.

Karanth, K. U. and Nichols, J. D. (1998). Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79(8), 2852-2862.

Karanth, K.U., Nicholds, J.D., 2002. Monitoring tigers and their prey. A Manual for researchers, managers and conservationists in Tropical Asia. Center for Widlife Studies. Bangalore. 193 pp.

Kautz, R., Kawula, R., Hoctor, T., Comiskey, J., Jansen, D., Jennings, D., Kasbohm, J., Mazzotti, F., McBride, R., Richardson, L. and Root, K. (2006). How much is enough? Landscape-scale conservation for the Florida panther. Biological Conservation 130, 118-133.

Kawanishi, K., Sunquist, M.E., 2004. Conservation status of tigers in a primary rainforest of Peninsular Malaysia. Biological Conservation 120, 329-344.

Kelly, M. J., Noss, A. J., Bitetti, M. S., Maffei, L.and Arispe, R. L. (2008). Estimating puma density from camera trapping across three study sites: Bolivia, Argentina, and Belize. Journal of Mammalogy 89(2), 408–418.

Laundré, J. W. and Loxterman, J. (2007). Impact of Edge Habitat on Summer Home Range Size in Female Pumas. American Midland Naturalist 157, 221-229.

Laundré, J.W., Hernández, L. and Clark, S.G. (2007). Numerical and demographic responses of pumas to changes in prey abundance: Testing current predictions. Journal of Wildlife Management 71, 345-355.

Lindzey, F.G. 1987. Mountain lion. In: Nowak, M. et al. (Eds.) Wild furbearer management and conservation in North America. pp. 657-668, Ontario Trappers Association, Toronto

Lindzey, F.G., Van Sickle, W.D., Ackerman, B.B., Barnhust, D., Hemker, T.P. and Lang, S.P. (1994). Cougar population dynamics in southern Utah. Journal of Wildlife Management 58, 619–624.

Logan, K.A. and Sweanor, L.L. (2001). Desert puma: evolutionary ecology and conservation of an enduring carnivore. Island Press, Washington, D.C.

Maffei, L. and Noss, A., 2008. How small is too small? Camera trap survey areas and density estimates for ocelots in the Bolivian Chaco. Biotropica 40, 71-75.

Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L. and Erickson, W.P. (2002). Resource Selection by Animals: Statistical Design and Analysis for Field Studies. Kluwer Academic Publishers, London, 240 pp.

McCain, E.B. (2008). Daily Activity Pattern of Moutain Lion (*Puma concolor*) in relation to the activity of their prey species in southern Arizona. Ms Dissertation, Faculty of Umboldt State University, 45 pp.

Moreno, R.S., Kays, R.W. and Samudio Jr., R. (2006). Competitive release in diets of ocelot (*Leopardus pardalis*) and puma (*Puma concolor*) after jaguar (*Panthera onca*) decline. Journal of Mammalogy 87(4), 808–816.

Morton, D.C., DeFries, R.S., Shimabukuro, Y.E., Anderson, L.O., Arai, E., Espirito-Santo, F., Freitas, R. and Morisette, J. (2006). Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceedings of the National Academy of Sciences 103(39), 14637-14641.

Moruzzi, T., Fuller, T. K., DeGraaf, R. M., Brooks, R. and Wenjun, L. (2002). Assessing remotely triggered cameras for surveying carnivore distribution. Wildlife Society Bulletin 30 (2), 380-386.

Nowell K. and Jackson P. (1996). Wild Cats: Status survey and conservation action plan. International Union for Nature Conservation (IUCN) /Cat Specialist Group, Gland, Switzerland: 110-113.

O´Brien, T., Kinnard, M.F. and Wibisono, H. T. (2003). Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. Animal Conservation 6, 131-139.

Otis, D. L., Burnham, K.P. White, C.G. and Anderson, D.R.. (1978). Statistical inference from capture data on closed animal's populations. Wildlife Monographs 62.

Pacheco, L. F., Lucero, A. and Villca, M. (2004). Dieta del puma (*Puma concolor*) en el Parque Nacional Sajama, Bolivia y su conflicto con la ganadería. Ecología en Bolivia 39(1), 75-83.

Peres, C.A. and Zimmerman, B. (2000). Perils in Parks or Parks in Peril? Reconciling Conservation in Amazonian Reserves with and without Use. Conservation Biology 15(3), 793-797.

Rabinowitz,1986. Jaguar predation on domestic livestock in Belize. Wildlife Society Bulletin 14, 170–174.

Rabinowitz, A.R., Nottigham, B.G., Jr., 1986. Ecology and behaviour of the jaguar (*Panthera onca*) in Belize, Central America. Journal of Zoology, London 210, 149-159.

Redford, K.H. and Eisenberg, J.F. (1992). Mammals of the Neotropics, Vol. 2: the southern cone. Univ. Chicago Press, Chicago.

Rexstad, E., and Burnham, K.P. (1991). User´s guide for Interactive Program CAPTURE. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, USA.

Rowcliffe, J.M. and Carbone, C. (2008). Surveys using camera traps: are we looking to a brighter future? Animal Conservation 11, 185-186.

Scognamillo, D., Maxit, I., Sunquist, M. S. and Polisar, J. (2003). Coexistence of jaguar (*Panthera onca*) and puma (*Puma concolor*) in a mosaic landscape in the Venezuelan llanos. Journal of Zoology, London 259, 269–279.

Sick, H. (1997). Ornitologia Brasileira, Editora Nova Fronteira, Rion de Janeiro, 912 pp.

Silveira, L. (2004). Ecologia comparada e conservação da onça-pintada (*Panthera onca*) e onça-parda (*Puma concolor*), no Cerrado e Pantanal. PhD thesis, University of Brasilia (Brazil). 240 pp.

Silveira, L. and Jacomo, A. T. (2002) Conservación del jaguar en el centro del cerrado de Brasil. In: Taber A. B., Chetkiewicz, C. B., Medellín, R., Rabinowitz, A. and Redford, K. H. (Eds.). El jaguar en el nuevo milenio. pp. 437–450. Fondo de Cultura Económica Universidad Nacional Autónoma de México and Wildlife Conservation Society, Distrito Federal, México.

Silveira, L., Jácomo, A. T. A. and Diniz-Filho, J. A. F., 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114, 351-355.

Silver, S.C., 2004. Assessing Jaguar abundance using remotely triggered cameras. Wildlife Conservation Socitey. 25 pp.

Silver, S.C., Ostro, L.E., Marsh, L.K., Maffei, L., Noss, A.J., Kelly, M.J., Wallace, R.B., Gómez, H. and Ayala, G. (2004). The use of camera traps for estimating jaguar *Panthera onca* abundance and density using capture/recapture analysis. Oryx 38 (2), 148-154.

Smallwood, K.S., and E.L. Fitzhugh. 1995. A track count for estimating mountain lions (*Felis concolor californica*) population trend. Biology Conservation 71(3), 251-259.

Soisalo, M.K., Cavalcanti, S.M.C., 2006. Estimating the density of a jaguar population in the Brazilian Pantanal using camera-traps and capture-recapture sampling in combination with GPS radio-telemetry. Biological Conservation 129, 487-496.

Stanley, T.R. and Burnham, K. P. (1999). A closure test for time-specific capture-recapture data. Environmental and Ecological Statistics 6, 197-209.

Sunquist, M. and Sunquist, F. (2002). Wild cats of the world. University of Chicago Press, Chicago, Illinois.

Sweanor, L.L., Logan, K.A., Bauer, J.W., Millsap, B. Boyce, W.M. (2008). Puma and Human Spatial and Temporal Use of a Popular California State Park. Journal of Wildlife Management 72(5), 1076-1084.

Trolle, M. and Kery, M. (2005). Camera-trap study of ocelot and other secretive mammals in the northern Pantanal. Mammalia 69, 409-416.

Waid, D. D. 1990. Movements, food habits, and helminth parasites of mountain lions in southern Texas. PhD thesis, Texas Tech University, 129 pp.

Wallace, R.B., Gomez, H., Ayala, G. and Espinoza, F. (2003).Camera trapping for jaguar (*Panthera onca*) in the Tuichi Valley, Bolivia. Mastozoological Neotropical 10, 5–11.

Wilson, S. M., Madel, M.J., Mattson, D.M., Grahamd, J.M. and Merrill, T. (2006). Landscape conditions predisposing grizzly bears to conflicts on private agricultural lands in the western USA. Biological Conservation 130, 47-59.

White, G.C., Anderson, D.R., Burnham, K.P. and Otis, D.L. (1982). Capture-recapture and removal methods for sampling closed populations. Los Alamos, National Laboratory Publication LA-8787-NERP, Los Alamos, New Mexico, USA.

Zielinski, W. J., Kucera, T. E. and Barrett R. H. (1995). Current distribution of fisher, *Martes pennanti*, in California. California Fish and Game 81, 104-112.

"...There would come a time, when the fish would die in the streams, the birds would fall from the air, the waters would be blackened, and the trees would no longer be, mankind as we would know it would all but cease to exist."
Old Cree Indian prophesy

CHAPTER 5

Private forest reserves can aid in preserving the community of medium and large-sized vertebrates in the Amazon arc of deforestation

Private forest reserves can aid in preserving the community of medium and large-sized vertebrates in the Amazon arc of deforestation

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Abstract

In consequence of the advance of the agricultural frontier present rate of deforestation in the Brazilian Amazon poses a pessimistic scenario for vertebrate diversity in the area. Protected Areas stand has an essential conservation tool to biodiversity loss but its efficiency is still to be proven. In this research we used observations and camera trap data on presence of medium and large-size vertebrates in a Protected area (Cantão State Park) and a neighbouring private forest reserve (Santa Fé Ranch) to evaluate this effectiveness and also gathered information on seasonality influence and activity pattern. A total sampling effort of 7929 trap-nights revealed a diversified vertebrate fauna in the region were mammals were photographed with more extent (65.7%), followed by birds (32.9%) and reptiles (1.4%). A total of 34 mammal species, belonging to 8 different Orders was detected in the study area during the all survey period, some of them of high level of importance in terms of conservation status like the giant otter (*Pteronura brasiliensis*) and the Uta Hick's Bearded Saki (*Chiropotes utahickae*). Data on photographic index showed that diversity was more abundant outside protected area and seasonality could play a major role in vertebrate occurrence inside Cantão State Park. Overall, seasonality seems to influence species distribution at a spatial level. During the wet season around 40% of the common species fail to be detected inside the park, meanwhile in Santa Fé Ranch most of the species (62.5%) suffered only a slight decrease in relative abundance due probably to change in availability in food resources. Our results highlight the importance of private land for vertebrate conservation in the Amazon and alert to need of increase in law enforcement for these areas in order to secure biodiversity preservation.

Key words: camera-trapping, tropical mammals and birds, Amazon, activity period

5.1- Introduction

With a growing human population and a higher demand for natural resources, protected areas stand as one of the main conservation measures used to avoid species extinction and habitat loss (Cardillo et al., 2004; Joppa et al., 2009). Presently with an area that reaches over 12% of earth terrestrial surface protected there are still some issues concerning efficiency of reserves in securing species richness preservation (Parish et al., 2003). One of the questions that remain open is the usefulness of private reserves in preserving the extraordinary biodiversity of tropical forests such as the Amazon. In Brazil, the agricultural frontier is quickly advancing in its fragmentation of the Amazon forest. By law, new farms and ranches need to establish a private forest reserve covering 80% of the private land which must be preserved. In theory, this legal requirement is preserving by far much more land than the more traditional public protected areas. However, it is not clear how useful they are in preserving biodiversity because most of our conservation and scientific efforts are focused towards public reserves.

The Amazon basin represents one of the most important regions in the world in terms of biodiversity (Costa et al., 2005; Stone et al., 2009). The largest rainforest of the planet leads the rank in the number of endemic species per area and shelters one of the highest diversities of vertebrates (IUCN et al., 2008). Habitat loss is the most important threat to vertebrate species and even if relatively well known, only a small amount of studies supply information on their status in this tropical forest (Voss and Emmons, 1996; Fonseca et al., 1999). The rate of deforestation of Brazilian Amazon has reached considerable high rates in recent years and it is estimated that the advance of the agricultural frontier over the region can cause a reduction of 50% of its forest cover in few decades and with it the majority of its vertebrate diversity (Laurence et al., 2001, Azevedo-Ramos et al., 2006). This scenario highlights the imperativeness of establishing an effective network of protected areas (Schulman et al., 2007). In particular in the "arc of deforestation", the eastern/south-eastern region of the Amazon, where an increased pressure of human occupation results in a highly fragmented landscape of agricultural farms and forest patches, we need to evaluate the conservation value of the remaining forest fragments (Lopes and Ferrari, 2000; Morton et al., 2006).

There as been an increase in research on the distribution and ecology of medium and large sized mammals and birds in the tropics but mammal' biological characteristics (nocturnal, low density and cryptic) make them difficult to census and study (Silveira et al., 2003; Lyra-Jorge et al., 2008). The use of camera trapping in surveys has been intensified recently due to its effectiveness in detecting and identified animals with inconspicuous habits accurately at a reasonable cost (Zielinski et al., 1995; Silveira at al, 2003; Kelly, 2008; Rowcliffe and Carbone, 2008). It constitutes a non-invasive method that contributes considerably with information on occurrence, population density and other biological parameters (sociality, activity or reproduction) of target and non-target species (Silveira et al., 2003; Gómez et al., 2006; Stein et al., 2008).

This research is part of a long-term monitoring program for jaguar density. Our intensive sampling efforts along several years resulted in a considerable number of photos of medium-large sized vertebrates, mostly mammals and to a limited extend birds within Cantão Sate Park (CS-Park) and the adjacent Santa Fé Ranch (SF-Ranch). Using this information we intend contribute with knowledge on the richness of this group of vertebrates, their activity patterns and the influence of seasonality and flooding both in a public reserve (CS-Park) and in a private forest fragment within a cattle ranch (SF-Ranch) in the Amazon arc of deforestation.

5.2- Material and Methods

5.2.1- Study Area

The study was carried out in the middle Araguaia river basin in two areas at opposite sides of the river: the Cantão State Park (CS-Park) in the right side and the Santa Fé Ranch (SF-Ranch) in the left side (Fig 5.1). Cantão State Park (09º36'S, 50º03'W) is an 89 000 ha conservation unit situated in the transitional area between the Amazon and the *Cerrado* biomes. Water abundance suffers a dramatic cyclical change due to an extent network of rivers, canals and lakes. The dynamics created by the wet season (November-March) and the prolonged dry season (April-October) influences vegetation structure (SPMA, 2000; Vitt et al., 2007). With an annual average precipitation of 1 710 mm/year and a difference of more than 4 meter in river level between seasons (data from Santa Fé Ranch), flooding conditions influence available resources (food and shelter) for the fauna (Fig. 5.2). The vegetation suffers from partial flooding during the wet season and is mainly represented by secondary growth tropical rainforest with some small areas being occupied by grasslands.

Santa Fé Ranch (09°34'S, 50°21'W) is a 65 000 ha beef cattle ranch in the southeast Pará State, margining the Araguaia River. Around 65 % of the ranch presents a continuous semi-deciduous seasonal tropical forest (similar as the CS-Park) patch that extrapolates the farm boundaries, while the other 35% is occupied almost entirely by pastures.

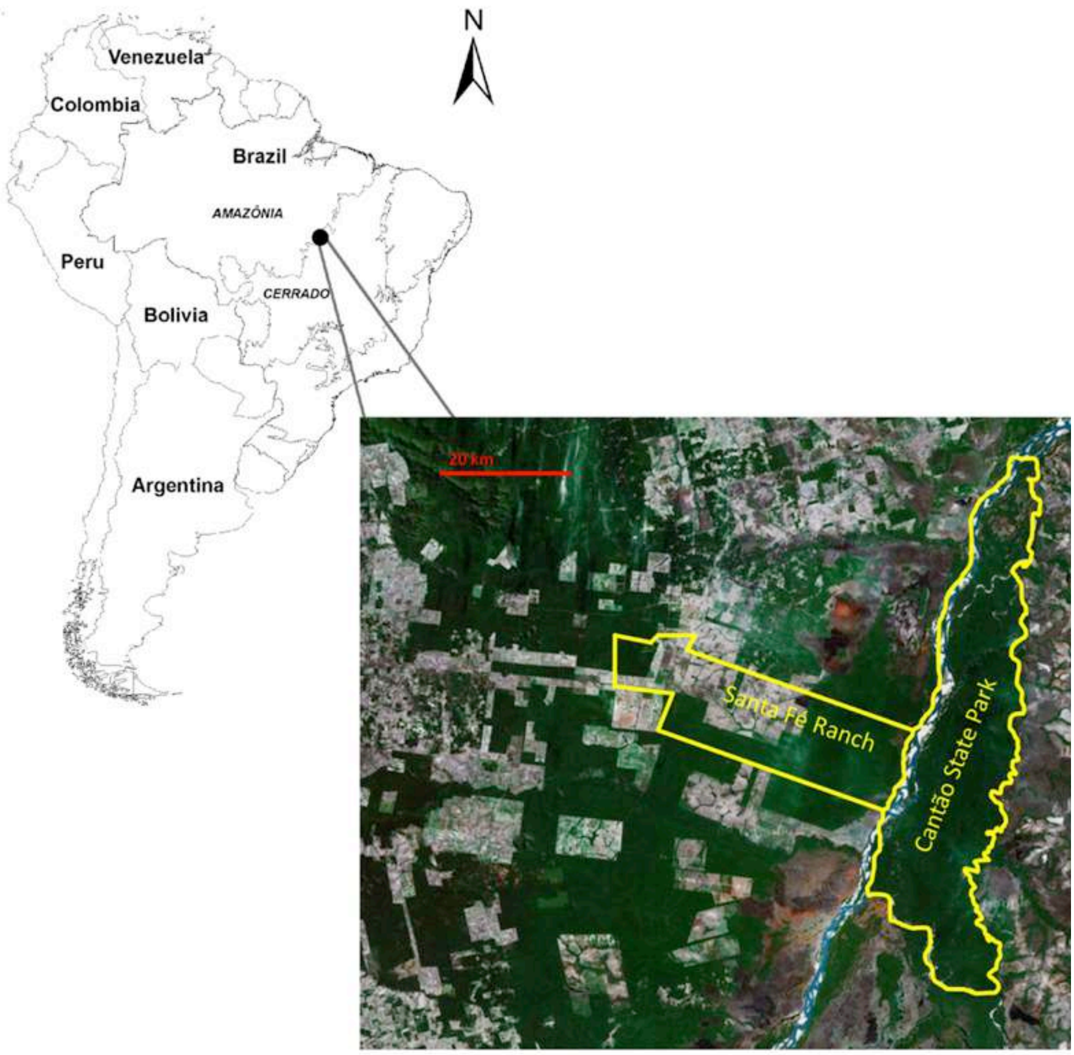


Figure 5.1 – Study area showing Santa Fé Ranch and Cantão State Park its ecotonal location in Brazil biomes Amazon and *Cerrado*.

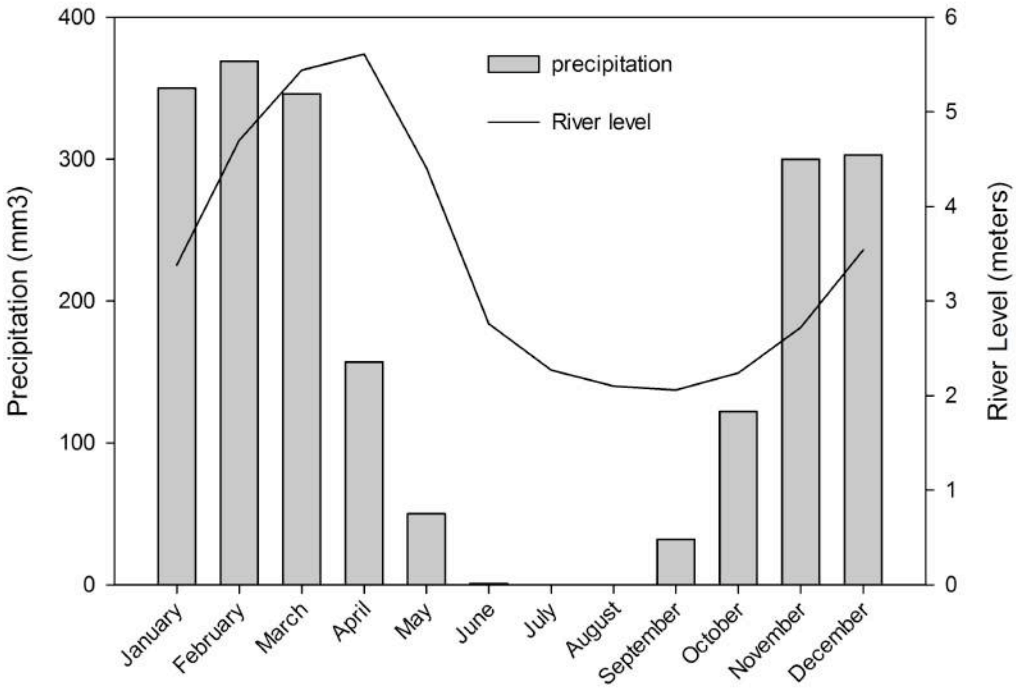


Figure 5.2- Precipitation and Araguaia River level for Cantão State Park region, central Brazil (data from Santa Fé Ranch).

5.2.2- Field methods

We conducted five camera trap surveys, between July 2005 and November 2007, during both the dry (three samplings) and wet (two samplings) seasons. A variable number of stations (from 10 to 22) were set throughout the area maintaining a distance between 1 km and 3 km (Rabinowitz and Nottigham, 1986; Karanth and Nicholds, 2002; Silver et al, 2004). Every station consisted of one passive infrared camera set on dirt roads or trails (animal or human made), at approximately 50-70 cm from the ground, except during the 2007 dry season sampling at SF-Ranch when we used two cameras per station (Silver, 2004). During the study two different camera types were used: Camtrakker® (Cam Trakker, Watkinsville, USA) and C1-BU® (Vibrashine Inc., Taylorsville, MS 3968, USA). Each camera was programmed to take photographs 24h/day with a 5-min interval between photos. All stations were checked on a regular basis (5-20 days) throughout all surveys for maintenance. In addition to camera trapping, field observations contribute data on the occurrence of primates and aquatic mammals during the expeditions for camera setting and monitoring.

5.2.3- Data Analysis

Species identification, number of individuals, sex, age, date and hour was determined for each photograph. Following O'Brien et al. (2003) photos were considered as independent events only if meet one of the three criteria: consecutive photographs of different individuals of the same or different species; consecutive photographs of individuals of same species taken more than one hour apart; non-consecutive photos of individuals of the same species.

The relative abundance index (RAI) was determined for all species by dividing the number of independent captures by effort (trap-nights) times 100 (O'Brien et al., 2003; Kawanishi and Sunquist, 2004). A photographic base index of abundance is considered a consistent method to infer the relative abundance of cryptic mammals, assuming that the cameras did not affect the movement rates of animals (Carbone et al., 2001; Goulart et al., 2009) The criteria used to set the cameras was always to maximise jaguar detection and therefore we can expect that the same bias in species detection occurs across all the study area, making the data comparable between sites and along time (Stein et al., 2008).

We anticipate that populations would remain relatively stable during our short period of time (3 years) and within seasons in the absence of any catastrophic phenomenon (Krebs, 1994; Harmnsen, 2006). Taking that into account, we pull together results from different samplings and compare RAI for the most frequent species between seasons (dry and wet) for both areas (SF-Ranch and CS-Park) using Mann-Whitney U-Test.

5.2.4. Factors affecting diversity and species Detection

Using generalised linear mixed models GLMM we evaluate the factors that could affect species richness according to sampling features (year, season, area: CS-Park vs. SF-Ranch) and environmental predictors (distance to water, distance to pasture, place were camera was set: road vs. trail), considering the number of different species as dependent variable and trap station included as a random variable. We also analysed the factors affecting RAI according to some species characteristics: weight, conservation status, trophic niche (predator vs. prey) and social behaviour (solitary vs group living), using RAI has dependent variable. Overdispersion was not a problem ($DF \approx 1.04$). We used the procedure GLIMMIX in SAS® (SAS Inst. Inc., Cary, NC) and R v.8.2 free statistical software and the Lme4 package for mixed models (Anon. 2005; Bates and Sarkar, 2006) to fit the statistical models.

5.2.5- Activity Patterns

We generated the activity pattern in 1-hour intervals for those species with more than 10 independent photographic events. We used Chi-square tests to compare data form CS-Park and SF-Ranch, pooling them together for further analysis if not significantly different ($p>0.05$). After that, each capture was classified into three categories (Schaik and Griffiths, 1996): nocturnal (18:31-05:00h), diurnal (06:31-17:00h), and crepuscular (17:01-18.30 and 05:01-06:30h).

5.3- Results

5.3.1- Species Richness

A total sampling effort of 7929 trap-nights were conducted over several continuous 2-months periods (average 61 days), with a variable number of camera stations (average 15; range 10-22) and trap nights (965 trap-nights; 525-1681) at each site (Table 5.1). Camera trap effort on CS-Park was lower (3183 trap nights) than in SF-Ranch (4746 trap nights) but sampling season lasted in both places on average 61 days, and the average number of camera stations set on each site was slightly higher in CS-Park (18) than in SF-Ranch (15). The difference occurs because in 2007 we only sampled SF-Ranch.

Mammals were the larger part of the photos identified (65.7%), followed by birds (32.9%) and reptiles (1.4%). The proportion nevertheless changes when considering the two study areas independently. In CS-Park birds reach 53.9% of the captures compared with 44.6% mammals and 1.1% reptiles. On SF-Ranch mammals were the most frequent group (70.2%) followed by birds (28.4%) and reptiles (1.4%).

Table 5.1- Sampling effort (n.º stations, n.º trap-nights, average number of days of effective camera use), total number of photos and number of photos (and percentage) for main vertebrate Class in Cantão State Park and Santa Fé Ranch in central Brazil, as determine from camera traps.

	Cantão State Park			Santa Fé Ranch				
	2005	2006		2005	2006		2007	
	Dry	Rain	Dry	Dry	Rain	Dry	Rain	Dry
Nº Stations	21	10	22	12	14	17	11	21
Total Effort (Trap-nights)	1390	626	1167	764	662	1114	525	1681
Mean Nº of Days	66	63	53	64	47	66	48	80
Nº Photos	136	37	94	136	80	220	100	724
Mammals	60 (*44.12*)	20 (*54.05*)	39 (*41.49*)	76 (*58.9*)	62 (*77.5*)	165 (*75.0*)	70 (*70.0*)	505 (*70.0*)
Birds	75 (*55.88*)	17 (*45.95*)	52 (*55.32*)	47 (*35.70*)	17 (*21.30*)	46 (*20.90*)	30 (*30.00*)	215 (*29.80*)
Reptiles	0	0	3 (*3.19*)	7 (*5.40*)	1 (*1.30*)	9 (*4.10*)	0	1 (*0.10*)
No Identified	0	0	0	7 (*5.40*)	0	0	0	3

A total of 34 mammal species, belonging to 8 different Orders was detected in the study area during the all survey period (Table 5.2). We registered more mammal species in SF-Ranch forest reserve (N = 30) than in CS-Park (N = 16), where some common species like brocket deers (*Mazama* spp.), peccaries (*Tayassu pecari* and *Pecari tacaju*), crab-eating fox (*Cerdocyon thous*) and armadillos (*Priodontes maximus* and *Dasypus novemcinctus)* were absent, contrary to the previous census done in the park by Silveira (2004).

In terms of conservation status we can emphasize the presence of two endangered species (EN), the giant otter (*Pteronura brasiliensis*) and the Uta Hick's Bearded Saki (*Chiropotes utahickae)*, and 3 species classified as vulnerable (VU) according to IUCN et al. (2008): the Tapir (*Tapirus terrestris*), the Marsh Deer (*Blastocerus dichotomus*) and the Giant Armadillo (*Priodontes maximus*) (Table 5.2). Two aquatic species, the Pink River Dolphin (*Inia geoffrensis*) and the Giant otter (*Pteronura brasiliensis*) were only present in CS-Park. Taking that into account and comparing the two sampled areas we can observe that SF-

Ranch presents 4 species classified under Threatened Categories (EN or VU) when CS-Park only presents 2 (Table 5.2).

Table 5.2 – Summary of mammal species recorded during several samplings (S) and previous one (S_0) in Cantão State Park (CSP) and Santa Fé Ranch (SFR) using camera trapping and occasional observations, together with respective IUCN (2008) and Brazilian National Red List (2005) conservation status.

				CSP		SFR
Species	**Common Name**	**IUCN**	**Brazil**	**S_0***	**S**	**S**
Blastocerus dichotomus	Marsh Deer	**VU**	VU		X	X
Mazama Americana	Red Brocket Deer	LC		X		X
Mazama gouazoupira	Gray Brocket Deer	LC		X		X
Pecari tajacu	Collared Peccary	LC		X		X
Tayassu pecari	White-lipped Peccary	**NT**		X		X
Inia geoffrensis	Pink River Dolphin	**DD**		X	X	
Cerdocyon thous	Crab-eating fox	LC				X
Speothos venaticus	Bush Dog	**NT**	VU			X
Puma yagouaroundi	Jaguarundi	LC		X	X	X
Leopardus pardalis	Ocelot	LC		X	X	X
Leopardus wiedii	Margay	**NT**	VU	X		X
Panthera onca	Jaguar	**NT**	VU	X	X	X
Puma concolor	Puma	LC		X	X	X
Eira Barbara	Tayra	LC		X		X
Pteronura brasiliensis	Giant Otter	**EN**	VU	X	X	
Nasua nasua	South American Coati	LC		X	X	X
Procyon cancrivorus	Crab-eating Racoon	LC				X
Didelphis albiventris	White-eared Opossum	LC		X	X	
Didelphis marsupialis	Black-eared Opossum	LC		X	X	X
Tapirus terrestris	Brazilian Tapir	**VU**		X	X	X
Alouatta caraya	Black Howler Monkey	LC				X
Cebus apella	Black-capped Capuchin	LC		X	X	X
Saimiri sciureus	Common Squirrel Monkey	LC				X
Callicebus moloch	Red-bellied Titi Monkey	LC				X
Aotus azarae	Azara's nigt monkey	LC			X	
Chiropotes utahickae	Uta Hick's Bearded Saki	**EN**	VU			X
Cuniculus paca	Spotted Paca	LC		X	X	X
Dasyprocta azarae	Azara's Agouti	**DD**		X		X
Coendou prehensilis	Brazilian porcupine	LC			X	X
Hydrochaeris hydrochaeris	Capybara	LC		X	X	X
Dasypus novemcinctus	Nine-banded Armadillo	LC				X
Priodontes maximus	Giant Armadillo	**VU**	VU			X
Myrmecophaga tridactyla	Giant Anteater	**NT**	VU			X
Tamandua tetradactyla	Collared Anteater	LC		X		X
Total Species	**34**			**21**	**16**	**30**

* data from Silveira (2004)

5.3.2- Photographic rate differences between places and seasons

All the species seem to be more abundant in SF-Ranch than in the CS-Park, with the exception of *Cuniculus paca* and *Crax fasciolata* (Table 5.3). When comparing RAI between seasons we can verify the absence of some species during the wet season like *Puma concolor*, *Mazama americana*, *Hydrochaeris hydrochaeris* and *Penelope* sp. inside CS-Park and *Mazama gouazoupira*, *Didelphis* sp., *Hydrochaeris hydrochaeris* and *Mitu tuberosum* in SF-Ranch. For CS-Park some species show a reduction (*Leopardus pardalis*, *Didelphis* sp. and *Crax fasciolata*) or increase (*Tapirus terrestris*, *Panthera onca* and *Cuniculus paca*) in RAI from dry to the wet season but the difference is only significant for the jaguar (*Mann-Whitney U-Test* W=32; $p<0.001$). Throughout seasonality the majority of the species that occur in SF-Ranch reveal a fluctuation in capture rates from the dry to the wet season. However only the reduction of *Mazama americana*, *Pecari tacaju*, *Cerdocyon thous*, *Leopardus pardalis*, *Dasyprocta azarae*, *Penelope* sp. and *Crax fasciolata* were significant (*Mann-Whitney U-Test* $p<0.05$ for all comparisons).

Table 5.3- Number of photos/100 camera-trap nights (± SE) for main individual mammal species in Cantão State Park and Santa Fé Ranch during wet and dry season and variation relative to dry season (⇑-increase; ⇓- decrease; X- non-detection).

	CS-Park			SF-Ranch		
	Dry	Wet		Dry	Wet	
Tapirus terrestris	1.136 (±0.284)	1.608 (±0.651)	⇑	2.582 (±0.585)	1.573 (±0.646)	⇓
Mazama gouazoupira				0.461 (±0.134)		X
Mazama americana	0.097 (±0.096)		X	2.207 (±0.391)	1.061 (±0.451)	* ⇓
Pecari tacaju				1.389 (±0.414)	0.066 (±0.066)	* ⇓
Cerdocyon thous				3.709 (±1.100)	0.197 (±0.144)	* ⇓
Leopardus pardalis	0.583 (±0.299)	0.154 (±0.154)	⇓	1.012 (±0.264)	0.191 (±0.132)	* ⇓
Puma concolor	0.095 (±0.053)		X	2.216 (±0.647)	2.064 (±0.553)	⇓
Panthera onca	0.173 (±0.074)	0.308 (±0.205)	* ⇑	4.957 (±0.738)	4.123 (±0.787)	⇓
Didelphis sp.	0.373 (±0.138)	0.154 (±0.154)	⇓	0.111 (±0.065)		X
Cuniculus paca	0.426 (±0.183)	1.072 (±0.562)	⇑	0.213 (±0.093)	0.301 (±0.226)	⇑
Dasyprocta azarae				3.209 (±1.304)	0.364 (±0.364)	* ⇓
Hydrochaeris hydrochaeris	0.297 (±0.228)		X	0.339 (±0.140)		X
Priodontes maximus				0.275 (±0.088)	0.358 (±0.303)	⇑
Penelope sp.	0.718 (±0.313)		X	1.868 (±0.510)	0.501 (±0.278)	* ⇓
Crax fasciolata	4.492 (±0.889)	3.076 (±1.029)	⇓	4.127 (±1.015)	1.724 (±0.813)	* ⇓
Mitu tuberosum				1.564 (±0.344)		X
Camera trap effort	2557	626		3412	1187	

* Significant differences determine using Mann-Whitey U-Test ($p<0.05$)

5.3.3- Biological and Sampling Factors affecting RAI

GLMM analysis revealed that number of species detected at each station was significantly higher outside the park than inside (Table 5.4). Also RAI increased during the sampled years, number of days of sampling and revealed a negative correlation with season (lower richness during the wet season). The place where the camera was set seemed to be of importance resulting in a higher number of species associated with roads compared to trails.

Table 5.4- Estimated coefficients and standard error (SE) for variables that influence species richness (total number of species) (model 1) and photographic rate (nº photos/100 camera-trap nights) (model 2) using GLMM analysis (*significant at 0.05; ** significant at 0.01; *** significant at 0.001).

			Estimate (±SE)
Model 1	(Intercept)		-0.0857 (±0.0157)***
	Days		0.0119 (±0.0031)***
	Area	*SF-Ranch*	0.3975 (±0.1705)*
	Year		0.4276 (±0.0784)***
	Season	*Wet*	-0.7521 (±0.141)***
	Place	*Trail*	-0.4230 (±0.1434)**
Model 2	(Intercept)		- 0.0199 (±0.1697)
	Weight		0.0092 (±0.0006)***
	Status	LC	-0.8340 (±0.0948)***
		NT	-0.4166 (±0.1079)***
		VU	-1.9013(±0.1714)***
	Trophic Niche		0.0071(±0.0538)
	Territorial Behaviour		-0.4908(±0.0554)***

The relationship between the photographic rate (RAI) and some species characteristics reveal that detection was positively and strongly dependent on the animal body mass (favouring large species) and aggregation (species that moved in groups) (Table 5.4). Considering that threatened level is somehow directly associated with abundance its logical that most endangered species (VU) species were less capture, has confirmed by negative correlation compare to less threatened ones. Trophic niche on the other hand did not present a significant association with RAI.

5.3.4- Activity Patterns

We determine the activity pattern for 16 species of mammals and birds. Most of them presented a nocturnal behaviour with exception of the gray brocket deer (*Mazama gouazoupira*), collared peccary (*Pecari tajacu*) and agouti (*Dasyprocta azarae*) (Figure 5.3). All the bird species presented crepuscular/diurnal behaviour. The jaguar was significantly more diurnal inside the park than in SF-ranch (χ^2= 55.71, DF=22, p<0.001). There were no differences in the activity pattern of the other common species between both areas.

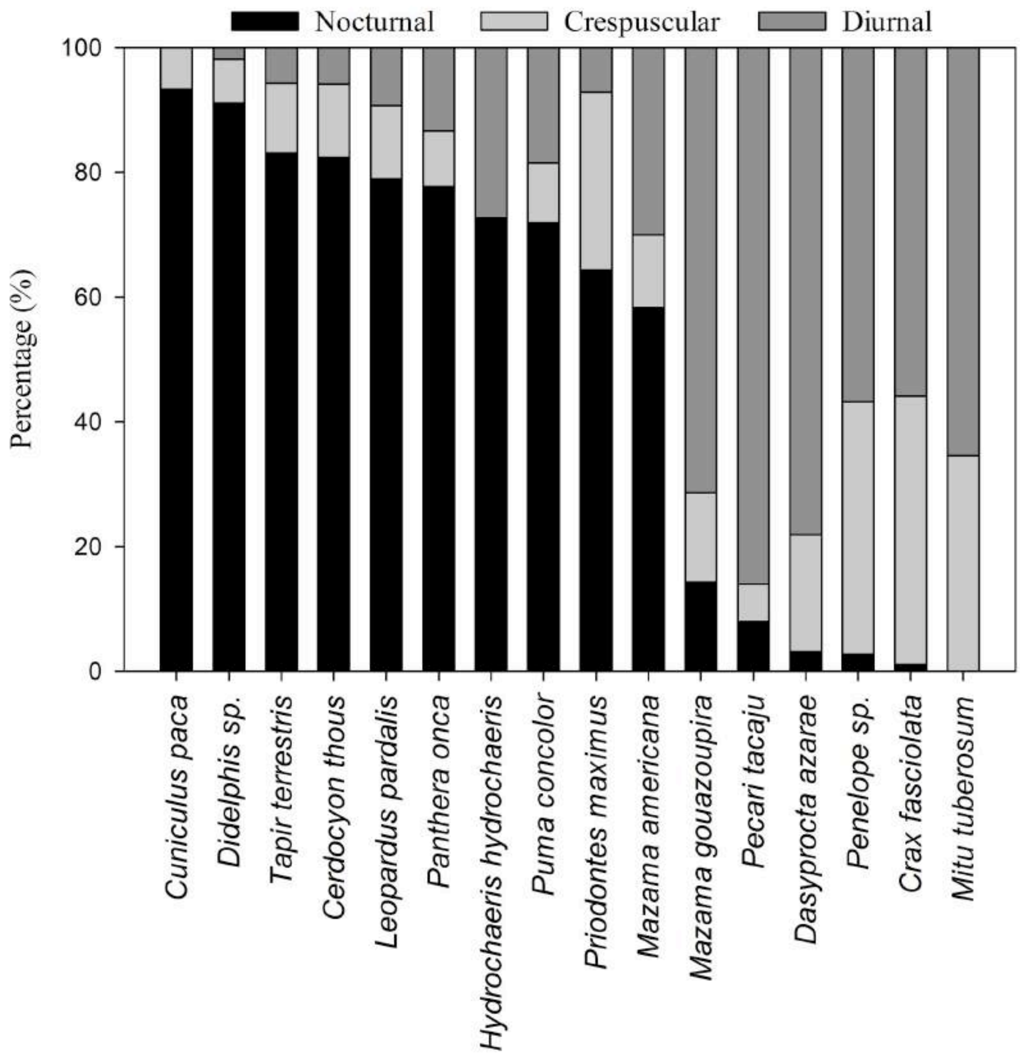


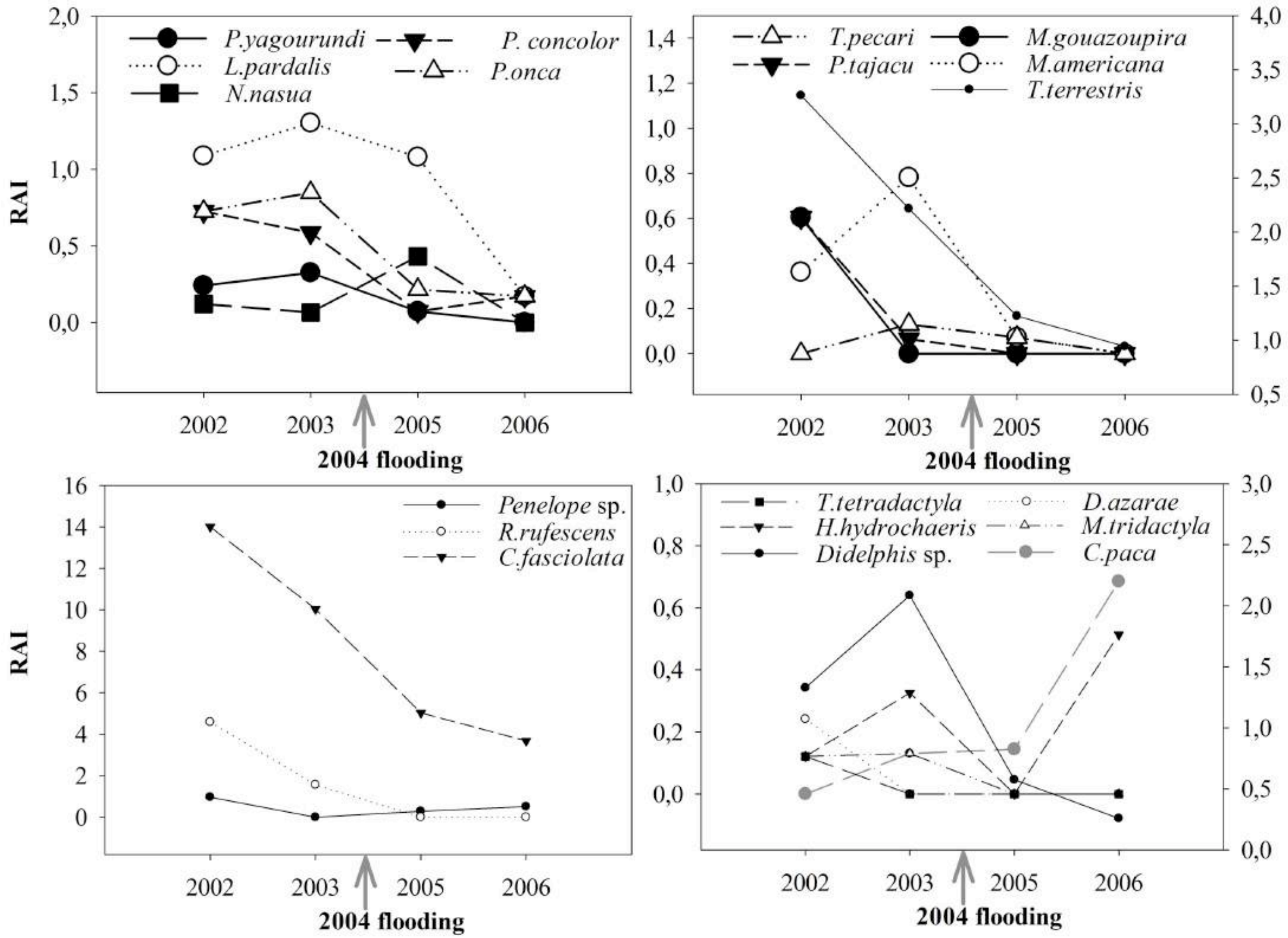
Figure 5.3- Activity pattern of some mammals and birds species in forest area central Brazil recorded by camera trapping (nocturnal 18:31-05:00h, diurnal 06:31-17:00h and crepuscular 17:01-18.30 and 05:01-06:30h).

5.4- Discussion

Photographic rate results are biased towards animals that spend most of the time on the ground, and since cameras were set to detect and evaluate jaguar density is also biased towards larger and more abundant animals, which makes the list of mammal species present in the area necessarily incomplete. Nevertheless it contributes with important information concerning the occurrence of mammals with different conservation status in the Amazonian agricultural frontier in a dramatic scenario were there is no room for complacency for about security of species not currently considered globally threatened (Cardillo et al., 2004). The activity patterns found in our study area is similar to the one described in the literature for the majority of the mammals species with a typical predominance of nocturnal species (Gómez et al., 2005). Nevertheless, like in CS-Park, jaguar can present a considerable daytime activity that could be associated to main prey species activity, in other areas on the Amazon and in Pantanal, (Schaller and Crawshaw, 1980; Crawshaw and Quigley, 1991; Gómez et al., 2005; Weckel et al., 2006).

CS-Park sufferers from a strong seasonal environment influence: its geographic position between the Araguaia and Côco Rivers makes the flooding regime during the winter season cover around 70% of its area (SMPA, 2000) making it very susceptible to catastrophic flooding or even droughts. The consequences in terms of habitat availability for terrestrial species are evident, forcing animal movements in search for more suitable places and causing probable seasonal differences in species occurrence and abundance inside the park. Comparing results on species richness in CS-Park with a previous inventory done by Silveira (2004) using the same methodological approach we can verify that 42.3% (N=21) of the mammal species previously referenced for the area fail to be detected in our 3 sampling periods conducted afterwards. The number of mammal photos actually decreased from 8-10 photos/100 trap nights to 3-4 photos/100 trap nights from 2002-2003 to 2005-2006, respectively. Also a decrease pattern can be observed in RAI from 2002-2003 to 2005-2006 for almost all the species, even with a superior sampling effort (2615 camera-nights for 2002-2003 an 3183 camera-nights for 2005-2006) (Figure 5.4). These differences can be explained by the extreme 2004 wet season that flooded almost the entire park in result of elevated precipitation and consequent increase of rivers water levels (Brazilian Water National Agency data). Probably during the 2004 flooding many populations of terrestrial mammals escape from CS-Park searching for suitable places above water, areas that are manly available in the surroundings of the park. Several local people accounts state observing abnormal number drowned animals and considerable number of animals crossing the river during that period.

Figure 5.4- Photographic rate fluctuation between different years of sampling in Cantão State Park for the most common mammal and bird species (2002-2003 data from Silveira, 2004).



If there is some deflation on mammal population inside the park during wet seasons it makes the re-colonization process totally depend on the level of habitat preservation in the surrounding areas, which is manly occupied by agricultural farms (with their forest reserves) and human rural settlements. Some species with higher mobility, like *Panthera onca* and *Tapirus terrestris*, may continue to use CS-Park during wet season, exploiting the small places that remain above water. Due to the reduced area with these characteristics, a concentration of activity in this space could result in the increase of capture rate (RAI) of this species. On the other hand other species due to severe flood in 2004 may have been extirpated from the CS-Park area and didn't manage to reoccupy the park since. After 2003 only *Cuniculus paca*, *Nasua nasua* and *Hydrochaeris hydrochaeris* showed an increase in RAI.

Forested reserve in SF-Ranch suffers less effect of the river flooding and animals distribution throughout seasons should be based on other resources availability namely food (Bodmer, 1990). In fact, the majority of species has a decrease in relative abundance during wet season, especially large herbivorous like *Mazama* sp., *Pecari tacaju*, *Tapirus terrestris*. Mendes Pontes and Chivers (2007) observed how in an area in central Amazon the fluctuation in food supply regulated the forest use by peccary species and consequently conditioned jaguar and puma whereabouts. With widely distribute food resources during the wet season peccaries exploited less frequently forested areas and presented a more broad scale space use. Our results concerning RAI variation within season for herbivorous species are coherent with these conclusions. In order to understand seasonality influence on mammals' movement in forest area in central Brazil further research should be performed enlarging the scale beyond forest limits supported by a carefully structured sampling design and taking into account food availability measures.

Our camera trapping research managed to reveal mammals' diversity in a region covering a protected area and a private one within the "arc of deforestation". The results highlight the importance of private forest reserves for mammal conservation and the misleading idea that nature reserve *per se* can secure species richness. On the other hand, private forest reserves can be more susceptible to pressure (e.g. deforestation and hunting) due to lower law enforcement, especially in the Amazonian agricultural frontier (Cardillo et al., 2004). This area has been attracting human migrations form different parts of Brazil, without careful planning, with consequently increase pressure on natural resources and no positive outcome neither socially neither environmentally (Olmos et al., 2007). In this region, for conservation measures to succeed combine action within protected areas and private should be established.

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References

Azevedo-Ramos, C. Do Amaral, B.D., Nepstad, D.C., Soares Filho, B. and Nasi, R. (2006). Integrating Ecosystem Management, Protected Areas, and Mammal Conservation in the Brazilian Amazon. Ecology and Society, 11(2): 17 [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art17/ Access in 15/5/2007

Bates, D. and Sarkar, D. 2006. Lme4: linear mixed-effect models using S4 classes, <http://www.R-project.org>.

Bodmer, R.E. (1990). Fruit patch size and frugivory in lowland tapir (*Tapirus terrestris*). Journal of Zoology. London 222, 121-128.

Carbone, C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J. R., Griffiths, M., Holden, J., Kawanishi, K., Kinnaird, M., Laidlaw, R., Lynam, A., Macdonald, D. W., Martyr, D., McDougal, C., Nath, L., O'Brien, T., Seidensticker, J., Smith, D. J. L., Sunquist, M., Tilson, R. and Shahruddin W. N. (2001). The use of photographic rates to estimate densities of tigers and other cryptic mammals. Animal Conservation 4(1), 75-79.

Cardillo, M., Purvis, A., Sechrest, W., Gittleman, J.L., Bielby, J. and Mace, G.M. (2004). Human population density and extinction risk in the world's carnivore. Plos Biology 2, 909-914.

Costa, L.P, Leite, Y.L.R, Mendes, S.L., Ditchfield, A.D. (2005). Mammal conservation in Brazil. Conservation Biology 19(3), 672-679.

Crawshaw, P.G. and Quigley, H.B. (1991). Jaguar spacing, activity and habitat use in seasonally flooded environment in Brazil. Journal of Zoology, London 223, 357-370.

Fonseca, G. A.B. da, Herrmann, G. and Leite, Y.L.R. (1999). Macrogeograhy of Brazilian mammals. In: Eisenberg, J. F. and Redford, K. H. (Eds.). Mammals of the Neotropics: the central Neotropics. Vol. 3, Ecuador, Peru, Bolivia, Brazil. pp 549-563. The University of Chicago Press, Chicago, USA

Gómez, H, Wallace, R.B., Ayala, G. and Tejada, R. (2005). Dry season activity periods of some Amazonian mammals. Studies on Neotropical Fauna and Environment 40(2), 91-95.

Goulart, F.V.B., Cáceres, N.C., Graipel, M.E., Tortato, M.A., Ghizoni, I.R. and Oliverira-Santos, L.G.R. (2009). Habitat selection by large mammals in southern Brazilia Forest. Mammalian Biology, doi:10.1016/j.mambio.2009.02.006

Harmsen, B.J. (2006). The use of camera traps for estimating abundance and studying the ecology of jaguars (*Panthera onca*). PhD Thesis, University of Southampton. 275 pp.

IUCN, Conservation International, Arizona State University, Texas AandM University, University of Rome, University of Virginia, Zoological Society London. 2008. An Analysis of Mammals on the 2008 IUCN Red List <www.iucnredlist.org/mammals>. Downloaded on 12 December 2008.

Joppa, L.N., Loarie, S.R. and Pimm, S.L. (2009). On population growth near Protected Areas. PLoS ONE, 4(1), e4279.

Karanth, K.U. and Nicholds, J.D. (2002). Monitoring tigers and their prey. A Manual for researchers, managers and conservationists in Tropical Asia. Bangalore: Center for Wildlife Studies, 193 pp.

Kawanishi, K. and Sunquist, M.E. (2004). Conservation status of tigers in a primary rainforest of Peninsular Malaysia. Biological Conservation 120, 329-344.

Kelly, M. (2008). Design, evaluate, refine: camera trap studies for elusive species. Animal Conservation 11, 182-184.

Krebs, C. J. (1994). Ecological Methodology. Addison-Welsey Educational Publishers Inc., 620 pp.

Laurence, W.F., Cochrane, M.A., Bergen, S., Fearnside, P.M., Delamonica, P., Barber, C., D'Angelo, S. and Fernandes, T. (2001). The future of the Brazilian Amazon. Science 291, 438-439.

Lopes, M.A. and Ferrari, S.F. (2000). Effects of human colonization on the abundance and diversity of mammals in eastern Brazilian Amazonia. Conservation Biology 14(6), 1658-1665.

Lyra-Jorge, M.C., Ciocheti, G., Pivello, V.R. and Meirelles, S.T. (2008). Comparing methods for sampling large- and medium-sized mammals: camera traps and track plots. European Journal of Wildlife Research 54,739-744.

Mendes Pontes, A.R. and Chivers, D.J. (2007). Peccary movements as determinants of the movements of large cats in Brazilian Amazon. Journal of Zoology, London 273, 257-265.

Morton, D.C., DeFries, R.S., Shimabukuro, Y.E., Anderson, L.O., Arai, E., Espirito-Santo, F., Freitas, R. and Morisette, J. (2006). Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceedings of the National Academy of Sciences 103(39), 14637-14641.

O´Brien, T., Kinnard, M.F. and Wibisono, H. T. (2003). Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. Animal Conservation 6, 131-139.

Olmos, F., Borges, C., Fernandez, F., Câmara, I., Sá Correa, M., Nunes, M., Milano, M., Rocha, S. and Theulen, V. (2007). Assentamentos da reforma agrária, meio ambiente e unidades de conservação. Available in: <http://arruda.rits.org.br/oeco/reading/oeco/reading/pdf/msc_olmos_mst.pdf>. Access in 03/10/2007.

Parrish, J.D., Braun, D.P. and Unnasch, R.S. (2003). Are we conserving what we say we are? Measuring ecological integrity within protected areas. BioScience 53, 851-860.

Rabinowitz, A.R. and Nottigham, B.G., Jr. (1986). Ecology and behaviour of the jaguar (*Panthera onca*) in Belize, Central America. Journal of Zoology, London, 210, 149-159.

Rowcliffe, J.M. and Carbone, C. (2008). Surveys using camera traps: are we looking to a brighter future? Animal Conservation 11, 185-186.

Schaik, C.P. and Griffiths, M. (1996). Activity periods of Indonesian rain forest mammals. Biotropica 28, 105-112.

Schaller, G.B. and Crawshaw, P.G. (1980). Movement Patterns of Jaguar. Biotropica 12, 161-168.

Schulman, L., Ruokolainen, K., Junikka, L., Sääksjärvi, I.E., Salo, M., Juvonen, S-K, Salo, J. and Higgings, M. (2007). Amazonian biodiversity and protected areas: do they meet? Biodiversity and Conservation 16, 3011-3051.

Silveira, L. (2004). Ecologia comparada e conservação da onça-pintada (*Panthera onca*) e onça-parda (*Puma concolor*), no Cerrado e Pantanal. PhD thesis, University of Brazilia (Brazil). 240 pp.

Silveira, L., Jácomo, A. T. A. and Diniz-Filho, J. A. F., 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114, 351-355.

Silver, S.C. (2004). Assessing Jaguar abundance using remotely triggered cameras. Wildlife Conservation Socitey. 25 pp.

Silver, S.C., Ostro, L.E., Marsh, L.K., Maffei, L., Noss, A.J., Kelly, M.J., Wallace, R.B., Gómez, H. and Ayala, G. (2004). The use of camera traps for estimating jaguar *Panthera onca* abundance and density using capture/recapture analysis. Oryx 38(2), 148-154.

SPMA- Secretaria de Planejamento e Meio Ambiente (2000). Avaliação ecológica rápida do Parque Estadual do Cantão. Governo do Estado do Tocantins, Palmas, Tocantins, Brazil. 133 pp.

Stein, A.B., Fuller, T.K. and Marker, L.L. (2008). Opportunistic use of camera traps to assess habitat-specific mammal and bird diversity in northcentral Namibia. Biodiversity and Conservation 17, 3579-3587.

Stone, A.I., Lima, E.M., Aguiar, G.F.S., Camargo, C.C., Flores, T.A., Kelt, D.A., Marques-Aguiar, S.A., Queiroz, J.A.L., Ramos, R.M. and Silva Júnior, J.S. (2009). Non-volant mammalian diversity in fragments in extreme eastern Amazonia. Biodiversity and Conservation 18,1685–1694.

Vitt, L.J., Shepard, D.B., Caldwell, J.P., Veira, G.H.C., França, F.G.R., Colli, G.R. (2007). Living with your food: geckos in termitaria of Cantão. Journal of Zoology, London 272 (3), 321-328

Voss, R. and Emmons, L.H. (1996). Mammalian diversity in Neotropical lowland rainforest: a preliminary assessment. Bulletin of the American Museum of Natural History 230, 1-115.

Weckel, M., Giuliano, W. and Silver, S. (2006). Jaguar (*Panthera onca*) feeding ecology: distribution of predator and prey through time and space. Journal of Zoology, London 270, 25-30.

Zielinski, W. J., Kucera, T. E. and Barrett R. H. (1995). Current distribution of fisher, *Martes pennanti*, in California. California Fish and Game 81, 104-112.

"Mankind differs from the animals only by a little and most people throw that away."
Confucius

CHAPTER 6
General Discussion and Conclusions

6.1- Wildlife-Human Interaction

Whenever an action conducted by human or wildlife has an adverse impact upon the other then conflict occurs (Conover, 2002). Recognizing the conflict and fully understanding the causes is the major step towards solving it and establishing a platform of coexistence in a sustainable way (Woodroffe et al., 2005). The creation of protected areas together with international agreements and Country/Regional law enforcement have been establish as the major options for ensuring the coexistence of man with wildlife (Woodroffe et al., 2005). The total area protected worldwide is 12% of earth surface (Parish et al., 2003). The global success of this strategy is still to be assessed in the years to come based on enhanced knowledge of biodiversity status and human impacts. In the meantime, technical information must be collected to fill up the gaps, and to allow us to evaluate present conservation strategies in order to improve actions and management plans.

6-2- Cantão State Park region: characteristics and conservation issues

The seasonal dynamics of the rivers contributes to the typical structure of the tropical forests in the Amazon: unflooded forests (hereafter, *terra firme*) and flooded forests (hereafter, *várzea*); where seasonality plays a major role in species distribution and abundance (Haugaasen and Peres, 2005). Nevertheless within each forest type there are several plant communities (Tuomisto et al., 2005) creating, together with edaphic factors, high habitat heterogeneity and promoting exceptional levels of diversity (Therborgh and Andresen, 1988). There is a lack of studies approaching the influence of flooded regime on species richness. The data collected so far points to the high importance of a joint contribution of *terra firme* and *várzea* for habitat heterogeneity, and the diversification of resource availability throughout space and time, that can support a recognizable amount of biodiversity (ter Steege et al., 2003; Haugaasen and Peres, 2005).

Cantão State Park (CS-Park) is located in the middle Araguaia river basin, surrounded by Araguaia and Côco rivers (Figure 6.1). Functionally CS-Park behaves like an extensive *várzea* since the majority of its area is flooded during the wet season by both rivers drainage. Consequently a reduced diversity and abundance of terrestrial mammals compared to *terra firme* areas is expected due to less floristic diversity and more forest homogeneity (Chapter 5 of this thesis; Haugaasen and Peres, 2005).

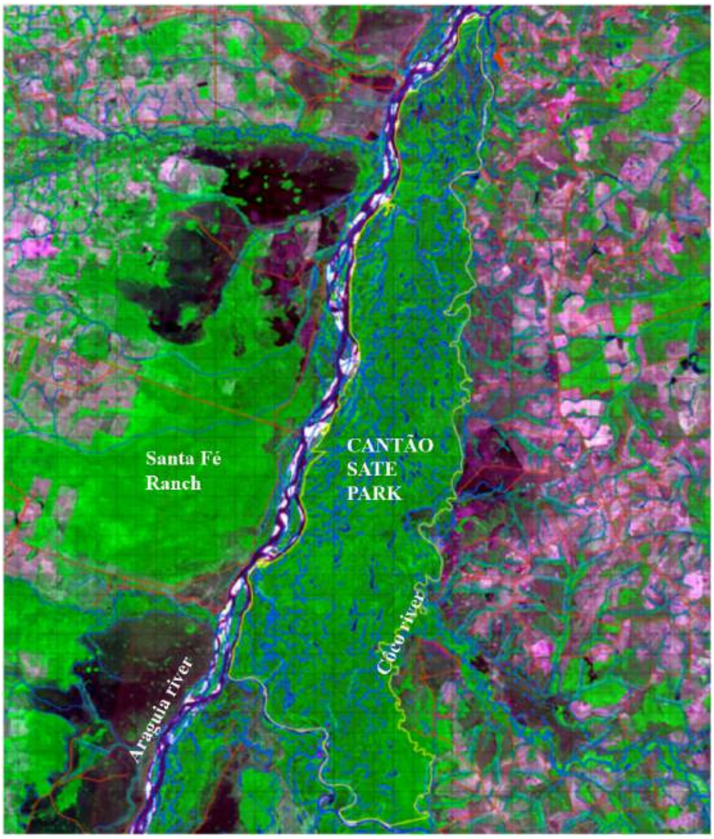

Figure 6.1- Satellite image of Cantão State Park region (source: Naturatins-TO).

During the wet season, the prolonged inundation (6 months) makes the majority of CS-Park inaccessible for terrestrial species (mostly mammals) highlighting the importance of the surrounding areas of *terra firme* for the re-colonization after flooding. This cyclic phenomenon has even more impact when exceptional flooding occurs, as in 2004 and, according to locals, in the 1980s.

Animal movement between CS-Park and surroundings should then be influenced by barrier effect caused by both rivers (Araguaia and Côco), and by species population status outside CS-Park, with potential for source-sink dynamics (Wiegand et al., 2005). Due to its larger size it is more likely that the Araguaia River is a bigger barrier than the Côco River. There is no information about the different permeability of these rivers to different species. Observations made during field research and locals account revealed that larger animals, like tapir (*Tapirus terrestris*), peccaries and large carnivores can cross both rivers, but we cannot determine with which frequency. For medium and smaller animals the Araguaia can stand as a bigger challenge. We can only speculate that animal movements would probably occur more frequently on the side of Côco River.

These seasonal migrations are also dependent on the population status and the spatially structured population dynamics, strongly connected to habitat availability outside CS-Park. Neighbouring the CS-Park there is a matrix of cattle ranch farms with different structural landscape composition and connectivity (Figure 6.1). The side of Côco River is occupied manly by pastures, with forested areas limited to several riparian galleries and some small forest patches. On the side of the Araguaia there is prevalence of an extensive forest patch (majority inside Santa Fé Ranch, state of Pará) and natural grassland (darker areas in the Figure 6.1) over the less extensive ranch pastures.

There is no data on the status of mammal diversity and abundance on the Tocantins area but results from camera trapping in Santa Fé Ranch (SF-Ranch) emphasize the importance of neighbouring areas for conservation of biodiversity in the region (Chapter 2, 3 and 5 in this thesis). Our results also suggest that jaguar and puma were more abundant in SF-Ranch and presented a more stable occurrence throughout the seasons (wet and dry) (Chapter 2 and 3). When compared with CS-Park mammal species richness was higher in SF-Ranch forested area, although seasonality seems to influence the occurrence of large herbivore species (Chapter 5).

We believe that as a protected area, the CS-Park efficiency in preserving mammal diversity is altogether dependent on the preservation of habitat and populations in neighbouring areas, in particular on the side of Côco River, were connectivity with the park seems higher. In a global conservation plan for the region other areas surrounding CS-Park should be integrated in order to secure full ecosystem preservation.

6.3- Law enforcement problems in the Cantão State Park region

Analyzing our results, it is indisputable that biodiversity conservation can only be enhanced by actions at private land management level and by an efficient enforcement of the law in what concerns forest reserves within farms. According to the Brazilian Forest Code for the Amazon region, farms can only be deforested 20% of total area, leaving 80% as forest reserve (except for *Cerrado* areas within the Amazon were the percentage of deforestation its allow to reach 75%). When a ranch is sold as one piece or splitted, the integrity of the private forest reserve should be enforced. The reality observed in the Cantão State Park surroundings is far from the legal requirements. We found many situations were large ranches were divided into several smaller properties, but failing to preserve the forest reserve area within mandatory size.

The lack of enforcement of law is also evident within rural settlements that are scattered around CS-Park area. Like for farms, the establishment of a rural settlement requires the establishment of a forest reserve (or several) with a size complying with the same law (80% for the Amazon region). In the Tocantins state there are various rural settlements established in the vicinity of Cantão State Park (28 in total, Olmos et al., 2007). All of them are obligated by law (CONAMA Resolution 289 from 25th October 2001) to have an environmental permit issue by the local environmental sate agency. This permit secures that the settlement respects all environmental laws (both state and federal), including forest reserve area and location. None of the settlements in the vicinity of CS-Park has this permit or either presents a forest reserve area that meets the law requirements (Naturatins, *Com. Pers.*). The federal agency responsible for the regulation and creation of settlements, INCRA, ranked in 2008 s the top 100 bigger deforester settlements in the Amazon. The two municipalities that border CS-Park on the Araguaia side, Santana do Araguaia and Santa Maria das Barreiras, are at the top of the list of the municipalities that deforest the Amazon region (measured as total area deforested in 2008, rate of increase of deforestation and total deforested area in the last 5 years equal or above 200 km^2). Additionally, there is a general complain about the lack of planning and support for the settlers, contributing to an exploitation of resources without any concern for sustainability (Silva and Martins, 2007).

We do not have any data on settlement impact on deforestation or mammal hunting exploitation in the CS-Park region but we can extrapolate from similar situations (Peres, 2001; Olmos et al., 2007). In other sites, inside and outside Amazon, the scenario is dramatic and that the increasing pressure on natural resources around and inside protected areas can seriously endanger its efficiency as a protected area and with it the ability to preserve biodiversity, without any real economical and social development for the communities (Olmos et al., 2007).

6.4- Large carnivore monitoring: a method and instrument for conservation

The use large carnivores as surrogate species in conservation, particularly focal species (Lambeck, 1997), can be useful to improve conservation efforts. Even if the benefits reach only a small portion of total biodiversity, this approach may still prove practical in mitigating specific threats such as habitat loss and fragmentation, and also in gaining social support from the charismatic impact that large carnivores have in different levels of the society (Karanth and Chellam, 2009).

Large carnivores, like the jaguar and puma, have been used as focal species due to their characteristics as top predators. We believe that monitoring the populations of these large cats in CS-Park region can be an advantageous instrument of conservation and management. The presence of both predators was associated with species richness (confirming them has potential umbrella species), both present a considerable high density (3.99 jaguars /100km^2 and 3.4 pumas/100km^2) and an apparent stable population in the area (Chapter 2, 3 and 4). It is expected that puma density would be lower in areas were jaguar occur at high density (Haines, 2006). In SF-Ranch we noticed a possible increase of puma population but not an apparent change in jaguar one (data from photographic index) and species seem to coexist probably by exploiting different food resources (Novack et al., 2005).

Our results highlight the need to follow some camera trap protocol specifications in order to monitor the jaguar and puma populations. First, camera traps should be set in pairs to allow individual identification (access to both flanks of animals) and correct estimation of number of individuals with a lower overall effort (Chapter 3). Secondly, camera stations should be set in roads and/or well-established trails that present high capture probability (using pilot study), and for the shake of annual comparisons, sampling locations and effort should be maintained (Chapter 2 and 4; Harmsen, 2006). Distance between cameras should be based on information on minimum animals' home-range size for the area that can be gathered throughout radio telemetry studies for both species. Several jaguar capture campaigns were carried out during fieldwork and three individuals were radio tagged with GPS collars. Due to equipment failure, no collar was recovered and data was lost. Nevertheless, we believe that an exhaustive effort for jaguar and puma radio tracking should be made using this previous experience as a baseline.

During this study the magnitude of the human-large carnivore conflict at local level was strongly evident. To address this issue a series of questionnaires to local people (farmers, settlers, hunter, etc.) was structured, part of a parallel project to understand human perspective on jaguar and evaluate depredation impact in the area (JCF and Nuno Negrões, *in prep.*). Preliminary analysis reveal that although damages on cattle never outweight 5% of the total herd, farmers' perception on predators, especially jaguar was far from positive. One of our radio-collared jaguars was killed due to direct persecution in consequence of cattle damages. Additionally, information supplied by local hunters allowed an estimation of a minimum of 60 jaguars killed per year in the Pará state area neighbouring CS-Park. Although preliminary, there is enough information to highlight the importance of approaching human-large cats conflicts to assess impact on jaguar and puma population in the area, and search for mitigation measures to minor the conflict.

The effective conservation of such species and biodiversity in general, hinges on actions that encompass both protected areas and private land, and in developing conservation-compatible land management strategies, including human-carnivore conflict reduction strategies (Nowell and Jackson 1996).

6.5- Human-Wildlife coexistence in the Amazon: a long road to walk

The importance of the Amazon for biodiversity and as a supplier of ecosystems goods and services, such as the atmospheric and climate stability of the planet is indisputable (Shukla et al., 1990; Foley et al., 2007). Protected areas comprise 46.4% of the 5 million km^2 of the Brazilian Amazon, including Federal and State Protected Areas, Indigenous land and Military areas, but it is not sufficient to protect Amazon biodiversity (Chapter 5 this thesis; Azevedo-Ramos et al., 2006). This consciousness is essential for the establishment of broad scale conservation plans and strategies that should address interdisciplinary actions from legislation (improve the effectiveness of law enforcement), environmental education, support local population with training and technical advices (towards sustainable development and environmental best practices), and target conservation actions (under focal species approach actions like recuperating degraded areas or mitigating large carnivores-human conflicts).

6.6-Further perspectives

Considering the dynamics of the CS-Park region there is the need to enlarge the study area to the neighbouring Tocantins side in order to evaluate the status of mammal populations in this region following camera trap protocol, taking into consideration issues described above.

To further understand animal movement within the entire region, especially during the wet season, animals should be monitored using radio tracking. The jaguar could be one species that should be tracked using telemetry since its wide range can help us in having a large-scale perspective on the animal movements. Also the knowledge of prey species movement, like tapir and peccary, could aid to understand flooding influence on mammal assemblage and also evaluate if predators follow prey in the seasonal activity. This telemetry study would generate additional information on the survival rates, which together with the analysis of the photo-trap history of the individuals along time should aid in identifying the actual status of the species in the area.

An extremely important study is the evaluation of the damages made by both wild cats on cattle, both from the socio-economic side and from the biological impact that this predation can have through the subsequent illegal poaching.

A deep study to determine rural settlements impact on fauna is also essential to further comprehend the human activities impact in the area. The research should be accompanied by an evaluation of the social situation and main problems attached, with the aim of establishing strategic plans for sustainable development within settlements, together with environmental education campaigns towards biodiversity conservation.

References

Azevedo-Ramos, C. Do Amaral, B.D., Nepstad, D.C., Soares Filho, B. and Nasi, R. (2006). Integrating Ecosystem Management, Protected Areas, and Mammal Conservation in the Brazilian Amazon. Ecology and Society 11(2): 17 [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art17/ Access in 15/5/2007.

Conover M. 2002. Resolving Human-Wildlife Conflicts: the science of wildlife damage management. CRC Press, Boca Raton, Florida. 418 pp.

Foley, J.A., Asner, G.P., Costa, M.H., Coe, M.T., DeFries, R., Gibbs, H.K., Howard, E.A., Olson, S., Patz, J., Ramankutty N. and Snyder, P. (2007). Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. Frontiers in Ecology and the Environment 5(1), 25-32.

Haines, A.M. (2006). Is there competition between sympatric jaguar *Panthera onca* and puma *Puma concolor*? Acta Zoologica Sinica 52(6), 1142-1147.

Haugaasen, T. and Peres, C.A. (2005). Mammals assemblage structure in Amazonian flooded and unflooded forest. Journal of Tropical Ecology 21, 133-145.

Harmsen, B.J. (2006). The use of camera traps for estimating abundance and studying the ecology of jaguars (*Panthera onca*). PhD Thesis, University of Southampton. 275 pp.

Karanth K.U. and Chellam, R. (2009). Carnivore conservation at the crossroads. Oryx 41(1), 1-2.

Lambeck RJ (1997) Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11(4), 849–856. doi:10.1046/j.1523-1739.1997.96319.x

Novack; A.J., Main, M.B., Sunquist, M.E. and Labisk. R.F. (2005). Foraging ecology of jaguar (*Panthera onca*) and puma (*Puma concolor*) in hunted and non-hunted sites within the Maya Biosphere Reserve, Guatemala. Journal of Zoology, London 267(2), 167-178.

Nowell K. and Jackson P. (1996). *Wild Cats: Status survey and conservation action plan.* International Union for Nature Conservation (IUCN) /Cat Specialist Group, Gland, Switzerland, 382 pp.

Parrish, J.D., Braun, D.P. and Unnasch, R.S. (2003). Are we conserving what we say we are? Measuring ecological integrity within protected areas. Bioscience 53, 851-860.

Peres, C.A. (2001). Synergistic Effects of Subsistence Hunting and Habitat Fragmentation on Amazonian Forest Vertebrates. Conservation Biology 15(6), 1490-1505.

Olmos, F., Borges, C., Fernandez, F., Câmara, I., Sá Correa, M., Nunes, M., Milano, M., Rocha, S. and Theulen, V. (2007). Assentamentos da reforma agrária, meio ambiente e unidades de conservação. Available in: <http://arruda.rits.org.br/oeco/reading/oeco/reading/pdf/msc_olmos_mst.pdf>. Access in 03/10/2007.

Shukla, J., Nobre, C and Sellers, P. (1990). Amazon Deforestation and Climate Change. Science 247, 1322-1325.

Silva, G.F. and Martins, A.K.E. (2007). Análise do uso e conservação da reserva legal do assentamento Pericatu, município de Pium-TO, utilizando geotecnologias. Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil. INPE, pp 3125-3131.

Terborgh, J. and Andresen, E. (1988). The composition of Amazonian forest: patterns at local and regional scales. Journal of Tropical Ecology 14, 645-664.

Ter Steege, H. Pitman, N., Sabatier, D., Castellanos, H., Van Der Hout, P., Daly, D. C., Silveira,M., Phillips, O., Vasquez,R., Van Andel, T., Duivenvoorden, J., De Oliveira, A. A., Ek, R., Lilwah, R., Thomas, R., Van Essen, J., Baider, C., Maas, P., Mori, S., Terborgh, J., Vargas, P. N., Mogollon, H. and Morawetz, W. (2003). A spatial model of tree alpha-diversity and tree density for the Amazon. Biodiversity and Conservation 12, 2255–2277.

Tuomisto, H. Ruokolainen, K. Kalliola, R., Linna, A., Danjoy, W. and Rodriguez, Z. (1995). Dissecting Amazonian biodiversity. Science 269, 63-69.

Wiegand, T., Revilla, E. and Kirk, M.A. (2005). Effects of Habitat Loss and Fragmentation on Population Dynamics. Conservation Biology 19(1), 108-121.

Woodroffe, R., Thirgood, S and Rabinowitz, A. (2005). The impact of human-wildlife conflict on natural systems. In: Woodroffe, R., Thirgood, S. and Rabinowitz, A. (Eds.). People and Wildlife: Conflict or Coexistence? Cambridge University Press, pp 1-12