Jaguars as landscape detectives for the upper Paraná River corridor, Brazil[1]

Laury Cullen Jr.[2]
- IPÊ- Instituto de Pesquisas Ecológicas

Kauê Cachuba Abreu
- IPÊ- Instituto de Pesquisas Ecológicas

Dênis Sana
- Associação Pró-Carnívoros

Alessandra Ferreira Dales Nava
- IPÊ- Instituto de Pesquisas Ecológicas

ABSTRACT

Many species living in fragmented landscapes are restricted to small natural habitat patches and form metapopulations; to predict their future is a central issue in applied ecology. We here present an analysis of the metapopulation dynamics of the jaguar *(Panthera onca)* for approximately 5,000 km2 of semi-connected and relatively well-preserved semideciduous Atlantic rainforests and marshlands of the upper Paraná River region. Using a combination of camera trapping and GPS/VHF telemetry, we present information on density, home range and habitat selection of the species. With the commercially available platform RAMAS/GIS 3.0, we developed a habitat suitability model for jaguars using data on topography, vegetation, and telemetry locations. With the habitat model, we then calculated the spatial structure of the jaguar metapopulation, including size and location of habitat patches and distance among them. Patch analysis identified three major habitat areas for jaguars and biodiversity conservation in the upper Paraná-Paranapanema region. Total jaguar population estimated for the region was about 45 individuals. The generated habitat map identified important stepping-stone areas that could be managed and restored to link jaguar populations in the near future. With most combinations of parameters, preliminary Population Viability Analysis (PVA) predicted decline and risk of extinction of the upper Paraná-Paranapanema jaguar population. In addition, our findings point out that, in the short term, increasing vital statistics for jaguar populations (greater fecundity and less mortality) seem to be more important than increasing dispersal rates among populations.

Keywords: jaguar, Atlantic Forest, upper Paraná River, ecology, metapopulation model, viability, landscape model, habitat fragmentation, patch analysis, RAMAS-GIS

INTRODUCTION

Isolated protected areas, such as national and state parks, often fail to conserve all elements of the natural biota, especially large mammals (Newmark, 1995). In fact, large mammals are particularly susceptible to extirpation even from well protected, but isolated, reserves. Keystone species, especially top carnivores, are essential to the maintenance of biological diversity and long-term ecosystem integrity (Soulé & Noss, 1998). There is increasing evidence suggesting that many ecosystems are regulated from the top by large carnivores, that ecosystems may collapse or be radically altered without them, and that ecosystem diversity and resilience will be lost as a result (Terborgh, 1999). For example, wide-ranging predators like jaguars (*Panthera onca*) often play essential roles in regulating the numbers and the diversity of prey

---

[1] Sent originally in English

[2] lcullen@stetnet.com.br

species in food chains. A large-scale approach to nature conservation calls for large, connected core reserves with their full complement of native species (Soule & Noss, 1998). The central goal of this approach is to maintain or to restore ecologically viable populations of large carnivores and other keystone species (Soulé & Terborgh, 1999, Foreman & Daly, 2000).

In this work, we propose to use the jaguar as a landscape detective, given the jaguar's ecological significance and need for extensive areas of protected, high-quality habitat. Landscape detective species can be defined as organisms that show us how to plan and to manage reserves and large interconnected eco-regions, because their requirements for survival include factors important to maintain ecologically healthy environments. More specifically, the main goal of this work is to use the jaguar as a landscape detective to develop a network of wild core reserves for the upper Paraná-Paranapanema Region in Brazil.

In the upper Paraná-Paranapanema region, jaguars exhibit a metapopulation structure. Metapopulation is defined here as a "network of isolated and semi-isolated populations with some level of regular or intermittent migration and gene flow among them, in which individual populations may go extinct but can then be recolonized from other populations" (Meffe & Carroll, 1997:678). Three major scientific arguments constitute the landscape detective approach and justify the emphasis on large predators, such as jaguars:

1) Prey diversity and density: the structure, resilience, and diversity of ecosystems is often maintained by "top-down" (trophic) interactions that are initiated and maintained by top predators (Terborgh, 1998, Terborgh *et al*, 1999). Specific prey species are key components of habitat for most large carnivores (Seidensticker, 1986). Therefore, by studying the jaguar prey-predator dynamics along with habitat selection we should be able to detect the prey structure, the resilience, and the diversity in areas where jaguars occur.

2) Large Core Areas: wide-ranging predators usually require space and large cores of protected landscape for secure foraging, seasonal movement, and other needs. By studying and comparing jaguar distribution and density in specific locations we should be able to detect core sections or habitat patches for the network of conservation areas. These areas should protect wild habitat, biodiversity, ecological integrity, ecological services, and evolutionary processes in the upper Parana-Paranapanema ecosystem.

3) Landscape Connectivity: connectivity is also required because core reserves are typically not large enough in most regions; therefore, they must be linked to ensure long-term viability of wide-ranging species. By tracking young dispersing jaguars that use forest patches as links in the fragmented landscape, we should be able to detect key and potential linkages between large natural areas. This could ensure the continuation of migrations and other movements vital for the survival of healthy populations and metapopulations of wildlife.

Ecoregional conservation planning that emphasizes the jaguar as a landscape detective, offers a novel approach to reserve design. This is a bottom-up approach that uses the jaguar to determine landscape conservation, which in turn should conserve the entire ecosystem, since top carnivores require a good prey base, large core areas and connectivity between the areas. It is certainly a major step beyond some current practices that include looking at a satellite image in an office and guessing where a core reserve, a habitat patch or a corridor should be. We are not proposing using a landscape detective approach as a surrogate for all species of concern. However, in the Upper Paraná Region, management decisions can not await the conclusion of long-term studies on more sedentary species. In this region, the use of data from GPS radio collared jaguars may be the most practical way to integrate biological information into the analysis of the negative impacts of fragmentation and mitigation attempts related to wildlife management, landscape ecology, and planning.

In 1997 we began a study of jaguar ecology and conservation in the Morro do Diabo State Park, a 370 km2 (37,000 ha) protected reserve in the Pontal do Paranapanema Region, São Paulo state. The area provides a unique opportunity to study jaguars as landscape detectives. Within the remaining western Atlantic Forest range, the Pontal do Paranapanema Region, together with the upper Rio Paraná ecosystem still maintains approximately 5,000 km2 of semi-connected and relatively well-preserved patches of semideciduous Atlantic forests and marshlands. It is included among the few areas where large carnivores such as jaguars, pumas and ocelots might persist (Sanderson *et al.*, 2002) (**FIGURE 1**). Jaguars are relatively common in the Pontal region (Cullen *et al.*, 2000, Leite *et al.*, 2002) and empirical information about their density, prey and habitat requirements, dispersal and metapopulation structure are needed to develop a landscape detective model based on robust and field species-specific natural history information.

Given the jaguar's critical status in the area, we need clear and reliable answers to some basic questions. These questions are linked to the three broad scientific arguments that constitute the landscape detective approach. 1. What is the absolute density of jaguars in high priority protected areas? 2. How do jaguars select habitats and what determines home range size and movement patterns? 3. What is the spatial structure of the jaguar metapopulation in the region; the location of these populations, size, initial abundance, carrying capacities and distance from each other? 4. What is the minimum area needed to secure viable jaguar populations and biodiversity conservation?

Figure 1: Unidades de conservação para a onça-pintada como sugerido por Sanderson et al. (2002).

METHODS AND RESULTS

Estimating jaguars density in the Morro do Diabo State Park

From March 2003 to August 2003 we conducted the first preliminary and systematic camera-trapping census of jaguars in the Morro do Diabo State Park, and obtained an unexpectedly large number of photos of jaguar, puma and ocelot. The survey was done by using modern camera-trapping equipment combined with capture-recapture analysis, a statistical technique for estimating population sizes from trapping data (Karanth & Nichols, 1998). Ten CAMTRAKKER Inc. camera-traps with infrared sensors were used. Traps were set up at natural travel routes for jaguars and their prey. Seven trapping stations were selected in a systematic grid system, covering approximately 90% of the area of the Park. The trapping stations were set to meet prerequisites of capture-recapture theory for reliable population estimates. The camera-trapping results were analyzed following the methodology outlined by Karanth and Nichols (2002) using the software CAPTURE (Rexstad & Burnham, 1991, Otis *et al.*, 1978) to estimate population parameters such as population size from recapture patterns of individually recognized individuals (**FIGURE 2**).

The data obtained from cameras are summarized as capture history data. During the study, there were seven trapping periods totalling 1,120 trap nights of effort and yielding 34 captures of six different individual adult and sub adult jaguars. These capture histories were used with the program CAPTURE to compute statistics related to the closure assumption and to model selection, as well as model-based estimates of abundance. The closure test statistic provided no evidence that the closure assumption was violated (z= 0.80, P=0.20). Thus, we concluded that the closed population models of CAPTURE were appropriate for these data and that we did not need to use models for open populations. Based on the discriminant function model selection procedure, models Mo and Mh were likely the most appropriate models for this data set. Based on field evidence that there could be heterogeneity in capture probabilities among different jaguar individuals because of social structure and unequal access to camera traps, we chose the M_h model (**TABLE 1**). Also, because of the robustness of the Jacknife Mh estimator to deviations from model assumptions (Otis et al., 1978) we felt that the estimates from this model were more appropriate.

Figure 2: Uma onça preta e uma pintada fotografadas no mesmo ponto de amostragem.

Table 1: Number of Jaguars at Morro do Diabo State Park based on camera-trapping survey

Captured probability estimate		Abundance		
Model	Per occasion	Number**	Stand. error	95% confiance inter.
M_o	0,28	6	0,69	6-8
M_h*	0,28	8	1,33	7-13

* Model selected
** Only adults and sub adults

The minimum number of jaguars in the population can be estimated directly from the numbers of different individuals recorded during camera trapping operations. Six individuals were recorded by camera trapping: two adult males, three adult females and one subadult. From the estimates using the selected model (M_h), the jaguar population density estimate (adults and subadults) from the Morro do Diabo State Park averages 2.22 individuals/100 Km^2 (SE 1.33). This figure is considerably lower than the estimates from the southern population in Iguaçu National Park in Paraná State (3.70 individuals/100 Km^2) (Crawshaw *et al.*, 2004). In the Brazilian Pantanal, there was an estimated density of 2.90 individuals/100 Km^2 (Schaller, 1983, Schaller & Crawshaw, 1980). In Belize, it was estimated that 20-30 jaguars were present in about 250 Km^2, a considerably higher density of 8 individuals /100 Km^2 (Rabinowitz & Nottingham, 1986). Silver et al. (2004), applying the same camera trapping methodology used in the present study, conducted a jaguar census in the Mayan rainforest of Belize, in the Chaco dry forest, and in the Amazonian rainforest of Bolivia. Densities ranged from 2.8 to 8.8 adult individuals per 100 Km^2. Based on these preliminary results, it is apparent and not surprising that jaguar density is lower in semideciduous habitats. The Morro do Diabo State Park is bordered by the dry Cerrado vegetation of Mato Grosso do Sul State and northern São Paulo State. Cerrado is tall dense semideciduous xeromorphic-like savanna vegetation. Morro do Diabo State Park is located right on the edge of the Cerrado and, accordingly, the best classification of the park’s forest would be an "upland semideciduous Atlantic Forest interspersed with some areas of Cerradão" (Baitello *et al.*, 1988). In these habitats, primary production is lower and more erratic and the availability of water is low, thus affecting the distribution and density of prey species (Cullen *et al.*, 2000).

Home range, habitat selection and movement patterns of jaguars in Morro do Diabo State Park

Specific methods

Jaguars were captured using custom-made iron box traps baited with live chicken or treed by trained dogs. Once trapped or treed, animals were chemically restrained with Zoletil (same as Telazol or CI-744; Virbac do Brasil). Locations from GPS (www.televilt.se) radio-equipped animals were downloaded from aircraft at approximately 70-day intervals. Triangulation was used to compute the VHF locations. Locations were plotted on a Landsat Satellite Image. Home ranges and movement patterns were estimated with the Animal Movement Analysis extension for ArcView GIS 3.3.

Home range and movements

During this preliminary phase, seven jaguars were captured and radio-collared, including two adult males and five females. All animals were captured in the Morro do Diabo State Park and surroundings. A total of 565 locations (85% GPS locations and 15% VHF locations) were obtained on the seven study adult animals, 195 (34%) for males and 370 (66%) for females. Home range estimates (Minimum Convex Polygon method) varied considerably for the study animals ranging from 43.79 Km^2 to 177.65 Km^2 (see **TABLE 2** and **FIGURE 3** for locations). Adult male jaguars moved on average 4.22 Km between locations and adult females moved on average 3.73 Km between locations. The mean interval in days between locations was one day for GPS and ten days for VHF collared animals. Average home size was 102.02 Km^2 (n=2) for males and 87.27 Km^2 for females (n=5). Average overlap area was 6 42 Km^2 (6%) for males and 16 Km^2 (18%) for females. Undoubtedly, some of this variation can be accounted by differences between sexes, age classes and habitat preferences.

The seven radio-collared animals used an area of approximately 300 Km^2. The estimated minimum density of adult and subadult animals in a four year period was therefore 2.33 jaguars/100Km^2, very similar to the 2.22 jaguars/100Km^2 estimate obtained from camera trapping.

In Belize, Rabinowitz and Nottingham (1986) using VHF radio telemetry, reported that home ranges of four males varied from 28 to 40 Km2, with an average of 33.4 Km2, about three times less than the average home range for males in Morro do Diabo. In the same study in Belize, two females had ranges of 10 and 11 Km2, respectively, or eight times less than those found for females in Morro do Diabo. In contrast to this study, the home range of the two females did not overlap in Belize, while those of the males overlapped extensively. Theory predicts that home range overlap in solitary male carnivores is expected if female density is low (Sandell, 1989). In Iguaçú National Park, in southern Brazil, home range estimates (MCP) varied considerably for the jaguars, ranging from 8.8 Km2 to 138 Km2 (Crawshaw et al., 2004). Again, these differences could be attributed to the lower carrying capacities of semideciduous habitats.

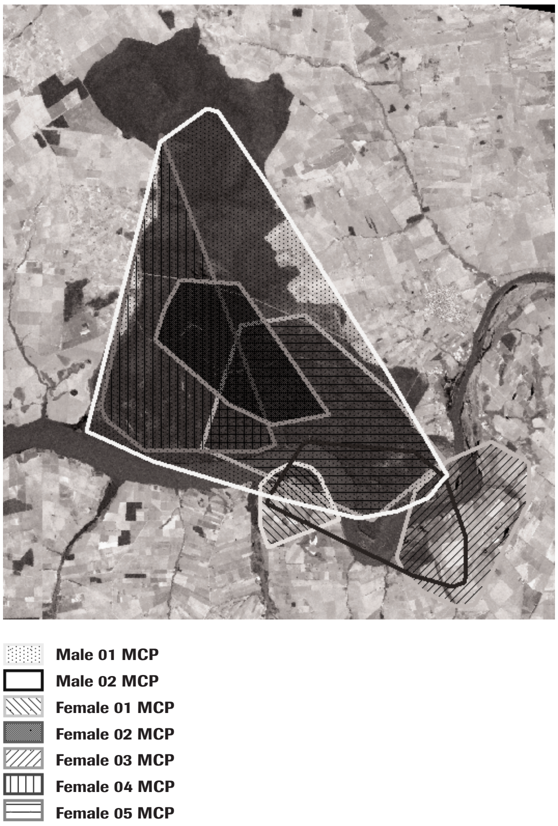

Figure 3: Territórios das onças com rádio-colar no Parque Estadual Morro do Diabo.

Habitat selection

The spatial structure of the jaguar metapopulation in the upper Paraná-Paranapanema ecoregion was based on habitat data. This link between habitat data and the metapopulation model is made possible by the spatial data program built in Ramas-GIS software (Akçakaya, 2002). This program uses spatial data on habitat requirements of the species, such as GIS-generated maps of land cover, and combines these data into map of habitat suitability (HS) with a habitat function. This map is then used to find habitat patches by identifying areas of high suitability where jaguar populations exist and might survive. The habitat and jaguar location data that formed the basis of this preliminary analysis are from the Morro do Diabo State Park and its surroundings.

Topographic map layers and habitat categories included mainly those most likely to explain jaguar habitat patches and metapopula-

Table 2: Home range sizes for radio-collared Jaguars in the Morro do Diabo Park

Jaguars	Dates tracked	Weight(kg)	Nº of locations	Home range size (km²) MCP
Fêmea 01	02/03-07/03	68	92	43,79
Fêmea 02	08/00-11/01	59	11	50,51
Fêmea 03	07/02-02/03	56	214	88,60
Fêmea 04	09/98-01/00	86	33	132,74
Fêmea 05	04/02-08/02	55	20	120,82
Macho 02	01/03-06/04	98	162	87,62
Macho 01	04/03-08/03	90	33	177,31

tion spatial distribution (**TABLE 3**). These maps were prepared by Alexandre Uezu (IPÊ GIS unit) from LandSat Images, using both ground knowledge and unsupervised classification of the three Landsat 7ETM satellite images that covered the span of the Morro do Diabo region. The analysis was done with the software Erdas Imagine 8.4 and Arcview 3.3/Spatial Analyst. We evaluated habitat selection as the distribution of all independent jaguar locations in each habitat type in relation to the habitat availability during the study period (**FIGURE 4**). Habitat selectivity was then defined by comparing availability (*A*)

Table 3: Habitat availability and selection by Jaguars in the Morro do Diabo

Habitat type	(A) Availability proportion in the study site (%)	(U) Proportion of Jaguars location (%)	IVLEV's index of selectivy	Selection
1- Water	4,89	4,03	-0,09663	-
2- Primary forest	2,56	12,63	0,66265	+++++
3- Secondary forest	2,95	7,79	0,45048	+++
4- Alluvial forest	1,27	2,41	0,30943	++
5- Dense marshland	3,06	6,98	0,38971	++
6- Open marshland	11,69	24,19	0,34810	++
7- Agriculture	21,84	34,40	0,22343	+
8- Pasture	51,70	7,52	-0,74584	- - - - - - -

+ (plus) and – (minus) indicate selection strength

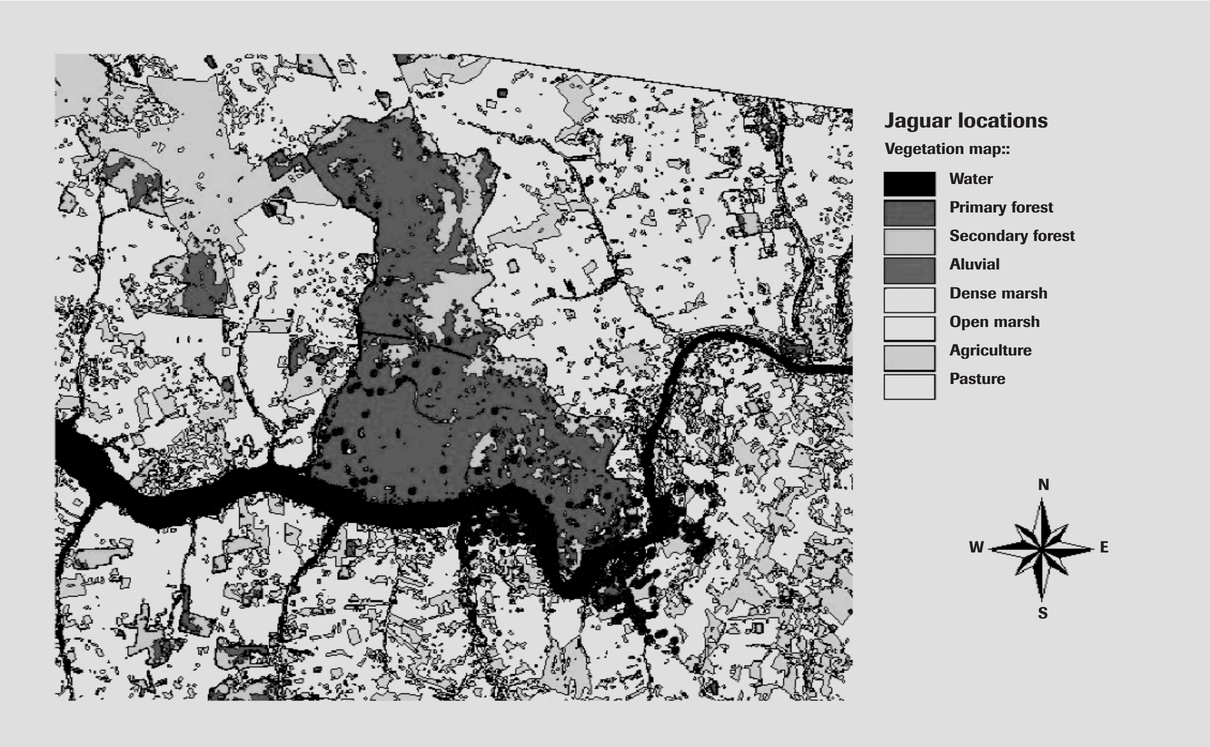

Figura 4: Seleção de hábitats de acordo com a distribuição de todos os pontos de ocorrência das onças em cada tipo de habitat e em relação à disponibilidade dos hábitats durante o período de estudo.

and utilization (U), using Ivlev's (1961) index of selectivity = $(U-A)/(U+A)$. Habitat selection was evaluated at gross scales (equivalent to the broad view of an animal's requirement), whether jaguar locations included in the habitat categories were in the same proportion to their availability in the study site.

Jaguars selected habitat types non-randomly in comparison to availability in the Morro do Diabo study area. Although primary and secondary forests together made up a very small percentage of the available habitat (5.51%), they were strongly selected for. Alluvial forests, dense and open marshlands also tended to be selected twice as much as availability. Agriculture and open water habitats were used roughly in accordance with availability. Open pasture was strongly selected against. With the continuation of this study estimates of ungulate density in each habitat will be available. This will allow us to correlate jaguar home range size, density, movements, and activity patterns, with that of prey and to incorporate prey-predator dynamics in the landscape detective approach. Also, during this study some cattle predation incidents were reported by farmers living around the park, but no evidence of wounded or shot jaguars was found. The livestock depredation impact and its relations to jaguar ecology in the study areas deserve investigation and will be considered during the continuation of this research.

These analyses highlight the relevance of forests and marshlands as key habitats for the survival of these last remaining jaguar populations in the upper Paraná-Paranapanema eco-region. Similar results also have been reported for other jaguar populations in Neotropical regions (Medellin *et al.*, 2002). We recommend that these habitats be given high priority in management and conservation strategies for the eco-region landscape conservation approach being developed by WWF and other partner institutions. Just as importantly, because forest and marshland habitats are the first disturbed by human intrusion, they act as potential fragmentation points. Trails, roads and irrigation canals are built and continued clearing of forest-marshland complexes may result in further fragmentation of these jaguar populations.

Metapopulation structure of jaguars in the Pontal do Paranapanema Region and the upper Rio Paraná ecosystem

An important step in the feasibility of the landscape detective model is to assess the metapopulation structure for the species in question. To describe the metapopulation structure of jaguars requires knowing where jaguars remain in relation to the size and spatial pattern of remaining forest cover, where there are barriers that separate breeding sub-populations, where habitat is degrading, and where humans have depleted the jaguar's prey base to the point that population size declines or jaguars become locally extirpated. Therefore, detecting large source areas where large and wide-roaming carnivores occur and might persist should be considered a key variable within the landscape detective approach. Vast areas of wild lands will be required for long-term viability of large carnivores (Shaffer, 1987). Where jaguar habitat is naturally or artificially fragmented, jaguars may exhibit a metapopulation structure. We hypothesize that the upper Paraná-Paranapanema River ecosystem holds a metapopulation of at least 50 jaguar breeders.

We present the preliminary analysis of the metapopulation dynamics of the jaguar for an approximately 5,000 Km^2 region of the upper Paraná-Paranapanema region. Using the software Ramas GIS, we developed habitat suitability (HS) model for this species using data on land cover and habitat selection of the species. With this habitat model we calculated the spatial structure of the metapopulation, including size and location of main habitat patches and the distances among them. We used a combination of our own data and literature review to estimate parameters such as survival, fecundity and dispersal and combined these parameters with the spatial structure to build a stage-structured, stochastic, spatially explicit metapopulation model. The model predicted a fast decline and high risk of extinction for the upper Paraná-Paranapanema populations with most combination of parameters. However, when the jaguar population from Iguaçu National Park, further south, is incorporated in the model, the whole metapopulation seems to be viable.

THE MODEL

We used the habitat selection results from the previous section to define our Habitat Suitability Function as:

Habitat Suitability (HS) =

$$0.022343*[agric]+0.030943*[aluv]+0.038971*[densemarsh]+0.034810*[openmarsh]-0.074584*[pasture]+0.066265*[primfor]+0.045048*[secfor]-0.0097*[water]$$

This function determines the suitability of a location given several input maps describing environmental variables. In other words, it attempts to identify habitat patches from the jaguars' point of view and tries to determine how the species perceives the patchiness of the landscape. This function is used to calculate the habitat suitability for each location (cell) in the map. The same vegetation map was used. Based on this map, we created eight data layers describing the proportion (%) of each habitat type in a grid cell of nine hectares (300 x 300 meters). References to map layers are within brackets in the habitat function.

The link between the habitat map and the metapopulation was characterized by two other parameters. Threshold habitat suitability (HS) was the minimum habitat suitability value below which the habitat is not suitable for reproduction and/or survival. Neighbourhood distances is used to identify nearby grid cells that belong to the same patch and may represent, for example, the mean foraging distance of the species. Based on field evidence of other jaguar locations along the whole basin, we used 2.0 as the threshold HS for jaguars in the upper Paranapanema region. This parameter was estimated based on the minimum HS value among grid cells in which we collected field evidence of jaguar reproduction (female with cubs). Based on telemetry results we used a neighbourhood distance of 12.40 cells (3,720 meters) as the mean foraging distance from the radio-collared jaguars.

The program Ramas allows the calculation of carrying capacities (K) based on the total habitat value of each patch. We estimated carrying capacities based on home range sizes and the camera trapping results (K=8 for Morro do Diabo, considering only adult and sub adult animals. Initial number (all adults, subadults and young individuals) for Morro do Diabo was estimated to be around 15 animals). Then, we specified the relationship between total habitat suitability values for the Morro do Diabo and K and initial numbers with a user built-in function. For this basic and preliminary model, no environment, demographic stochasticity and catastrophes were considered. For simulations, we assumed a ceiling-type density-dependent model for each population and used the carrying capacities calculated based on habitat data as population ceilings. The effects of jaguar dispersal on the analysis of viability were also modelled and refer to the movement of jaguars (subadult individuals) among habitat patches. A dispersal rate of 10% (proportion of individuals dispersing from one population to another) was initially used in this preliminary analysis. The analysis of the dynamics of the jaguar population with the model described above consisted of a series of simulations. Each simulation consisted of 1,000 replications and each replication projected the abundance of each population for 100 time steps (years). A sensitivity analysis was performed considering changes in survival rates and K in the jaguar populations.

Given the habitat map and the parameters described above, the program found three habitat patches (clusters of suitable cells within the neighbourhood distance of each other).

The patch structure found was very realistic considering the remaining habitat, jaguar known occurrences and the location of some protected areas in the upper Paraná-Paranapanema region. Carrying capacities, initial abundance and areas of patches identified by the model are presented below (**TABLE 4**, **FIGURE 5**).

Total jaguar population estimated for all patches was about 45 individuals, with a carrying capacity of 30 considering only adults and sub adults. The largest patch (#2) with an area of 976 Km2 comprise the Ivinhema State Park region and a large area to the south towards the Ilha Grande National Park, where considerable jaguar populations are known to persist.

Table 4: Carrying capacities, initial abundances and areas of patches identified by the model

Patch #	Location	K*	Init. abund.	Total HS	AVG. HS	Area (km^2)	Area as 5 of patches
1	Morro do Diabo	9	14	20678	5,30	351	19,61
2	Ivinhema	14	21	32256	2,97	976	54,47
3	Ilha Grande	7	10	15273	2,96	465	25,92
TOTAL		30	45	68207	3,74	1792	100,00

K = only adults sub adults, Init. Abundance = all individuals

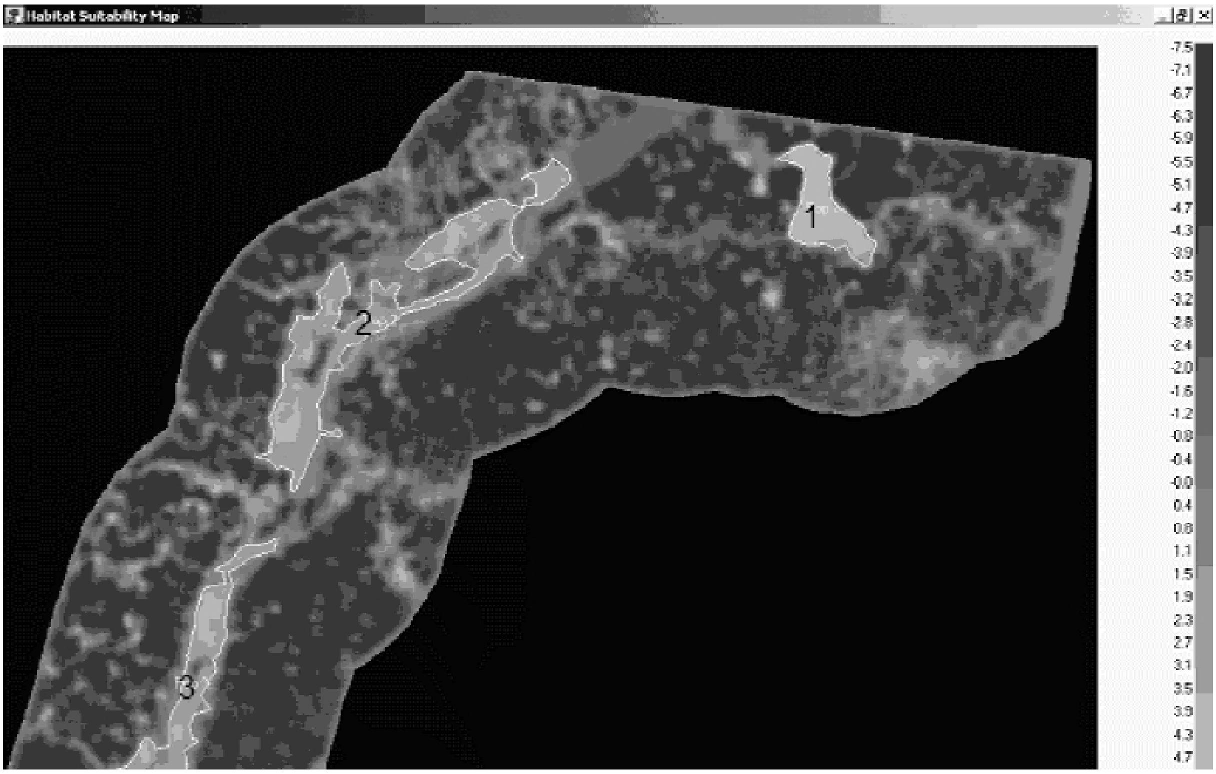

Figure 5: Estrutura das manchas das populações de onças-pintadas na região do Alto Paraná-Paranapanema. Os valores do potencial de adequação do habitat estão representados na escala à direita da figura, com os valores variando de –7,5 (menos adequado) até + 6,8 (mais adequado). O delineamento em branco representa o limite externo das manchas 1, 2 e 3. A mancha 1 corresponde à área do Parque Estadual Morro do Diabo; a mancha 2, ao Parque Estadual de Ivinhema; e as várzeas mais ao sul e a mancha 3 correspondem à área do Parque Nacional de Ilha Grande.

This patch made about 54% of the total area of all patches. Only 2.6 % of the total landscape analysed is covered by the three suitable patches found, a very small area considering jaguar area requirements. Patches have gaps between them, which represent unsuitable locations when we consider jaguar's habitat requirements and foraging distance. These gaps might affect landscape connectivity and dispersal between patches. The habitat suitability map also has the great potential to be used to identify stepping-stone corridors - cells with high suitability value outside the patches identified - linking jaguar subpopulations and contribute to the design and restoration of an interconnected landscape.

Population Viability

With most parameter combinations, the model predicted a decline and high risk of extinction of the upper Paraná-Paranapanema jaguar population (**FIGURES 6-9**). The risk of falling below the metapopulation threshold of 10 individuals was about 80% in 80 years. Median time to extinction is 88 years.

A surprising result was the negative, albeit weak, effect of natural dispersal and managed dispersal (translocation). When dispersal is modelled among the three patches (allowing 10% dispersal rates between patches and some translocations were natural dispersal is very unlikely) the model produces outputs with very similar results, with no significant difference between the two scenarios (**TABLE 5**; **FIGURE 10**). This can be explained by the type of source and sink dynamics (Alçakaya and Atwood, 1997). Although all populations in the model have similar vital rates (hence similar lambdas), the smaller populations were more prone to extinction as a result of demographic stochasticity. Therefore, increasing dispersal meant dispersing jaguars going from more stable, larger populations, to smaller and more extinction-prone populations.

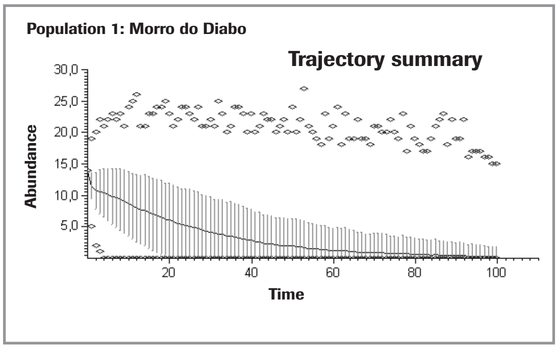

Figure 6: Resumo da trajetória da população do Morro do Diabo.

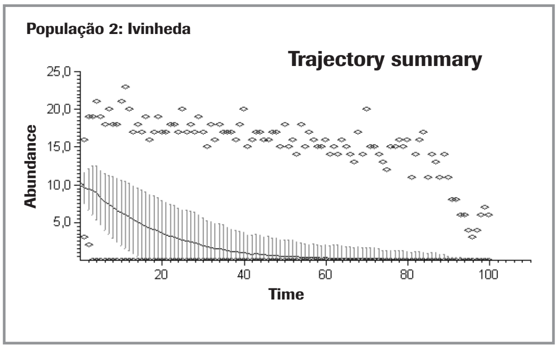

Figure 7: Resumo da trajetória da população da mancha de Ivinhema.

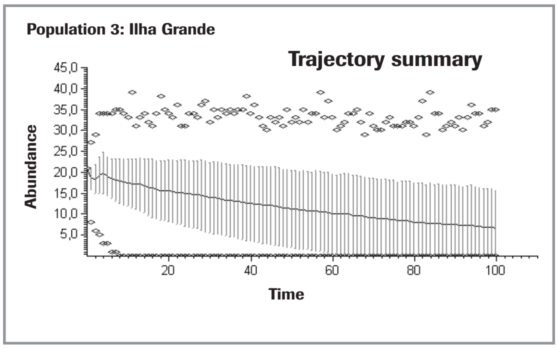

Figure 8: Resumo da trajetória da população da mancha de Ilha Grande.

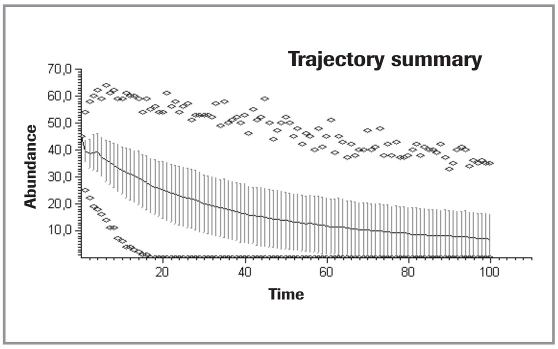

Figure 9: Resumo da trajetória da Metapopulação.

However, sensitivity analysis showed significant results when dispersal is combined with a 15% increase in population vital rates (increasing survivals rates by 15% and decreasing mortality rates by 15%. The metapopulation is likely to persist for the next 100 years and stabilize around 40 individuals when we consider this scenario (**FIGURE 11**).

Another aim of this analysis was to demonstrate any change in the viability by adding another population to the upper Paraná-Paranapanema jaguar metapopulation. This was done by including in the simulations the southernmost protected jaguar population in Brazil – the Iguaçu National Park. The values used for population carrying capacity for Iguaçu was K=40 and initial abundance of 67 individuals (Crawshaw *et al*., 2004). Considering this scenario, it is also very important to emphasize that jaguar natural dispersal between Iguaçu and the upper Paraná-Paranapa-

Table 5: Sensitivity results to different parameters and scenarios used when modelling the viability of the upper Paraná-Paranapanema Jaguar metapopulation, with the ramas software

Parameter/Scenario	Efect	Terminal [A] extinction risk	Metapo [B] Occup. B	MDO	IVO	IGO
Base Model	-	65%	12	2	8	2
Base Model + 10% dispersal rate	-	100%	5	1	3	1
Base Model + 10% dispersal rate + 15% vital rates	+	1%	42	12	20	10
Base Model + nat. dispersal + Iguaçu park	+	0%	65	3	3	6
Base Model + 10% Nat. dispersal + transloc + Iguaçu	+	0%	74	10	11	6

[A] Shows the probability that the metapopulation abundance will end up below a threshold number of 10 individuals 50 years from now;
[B] Metapopulation occupancy: shows the total number of individuals the metapopulation is likely to have 50 years from now;
MDO= Morro do Diabo Area occupancy in 50 years;
IVO= Ivinhema Area occupancy in 50 years;
IGO= Ilha Grande Area occupancy in 50 years.
Transloc= translocations or managed dispersal at 10 % rate among all populations.

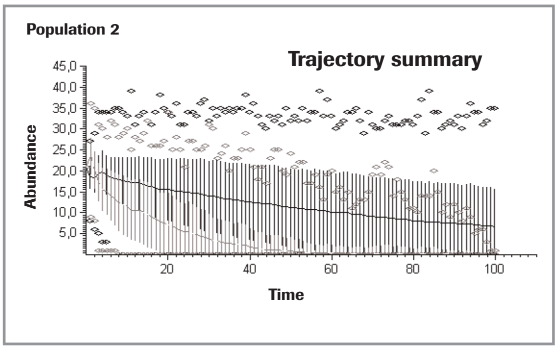

Figure 10: Efeitos da dispersão (linha verde) na população de Ivinhema, a qual mostra os resultados de onças migrando de populações maiores e mais estáveis para populações menores e com maior probabilidade de extinção.

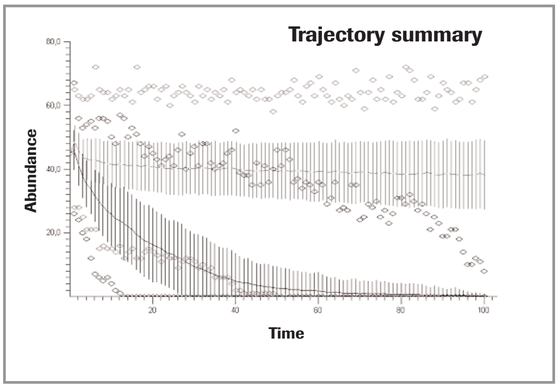

Figure 11: Trajectory summary of the metapopulation when dispersal is modelled in combination with a 15% increase in population vital rates.

nema region is possible, when one considers dispersal distances of the species and the major forest restoration programs being carried out along this corridor. Model results showed positive effects, mostly if we also include translocation in a management program in combination with natural dispersal where it is considered feasible.

DISCUSSION

Considering the preliminary patch analysis, we may conclude that using large carnivores such as jaguars as landscape detectives appears to be a good method to identify large core areas and important wildlife reserves for biodiversity conservation. It is a bottom-up methodology that uses the animal's view to determine landscape conservation, which in turn should conserve the entire ecosystem, since top carnivores require a good prey base, large core areas and connectivity between populations.

Camera trapping census estimated jaguar population (adults and subadults) for the Morro do Diabo State Park to be about 2.22 individuals/100 Km^2. This estimate is low when compared to other studies in Iguaçu and Pantanal in Brazil, but similar to estimates obtained from other Neotropical areas. These differences could be attributed to the lower productivity of inland semi deciduous Atlantic Forests bordering the cerrado vegetation, thus affecting the distribution and density of prey species. Patch analysis identified three major habitat areas for jaguars and biodiversity conservation, which was consistent to known jaguar occurrence and location of protected areas in the upper Paraná-Paranapanema region. Only 2.6 % of the total landscape analysed is covered by the three suitable patches found. Total jaguar population estimated for the eco-region was about 45 individuals. Gaps found between patches might affect landscape connectivity and dispersal between patches. However the habitat map identified important stepping-stone areas that could be managed and restored to approximate and to link jaguar populations in the future.

With most parameter combinations, preliminary population viability analysis (PVA) predicted decline and risk of extinction of the upper Paraná-Paranapanema jaguar population. The risk of falling below the metapopulation threshold of 10 individuals was about 80% in 80 years. Median time to extinction was 88 years. Noteworthy was the negative effect of natural dispersal. When dispersal is modelled among patches, the model produces results very similar to those explained by the type of source and sink dynamics of small and unstable populations. Sensitivity analysis showed significant results when dispersal is combined with a 15% increase in population vital rates (increasing survivals and decreasing mortality rates) and/or considering the Iguaçu National Park population in the plan. The metapopulation and all identified populations are likely to persist and stabilize when this scenario is considered. In practical terms, in the short term, increasing jaguar vital statistics means avoiding poaching and jaguar-human conflicts, protecting prey populations, thus increasing carrying capacity, and enforcing rules and regulations in protected areas and habitat patches identified in this study. Increasing both natural and managed dispersal is recommended for the mid-long terms.

These preliminary findings in this long-term jaguar research stress the importance of increasing vital rates for jaguar populations. In the short term, increasing vital rates (more fecundity and less mortality) seems more important than increasing dispersal rates. Increasing dispersal, specifically for the upper Paraná-Paranapanema metapopulation is only recommended once we reach the point of more stable jaguar populations. The sensitivity of this analysis suggests that these preliminary results should not be interpreted in absolute terms. Especially, it would be inappropriate to use these results to conclude that the jaguar metapopulation in the upper Paraná-Paranapanema basin is in threat of extinction. There is simply too much uncertainty about most of the parameters to predict with confidence what the population size will be in 50 years or what the risk of extinction might be. Despite this uncertainty, these models can have practical use in two ways (Alçakaya & Atwood, 1997): 1) they provide information about which parameters need to be estimated more carefully and where funds and field work effort should concentrate, 2) they allow us to rank management options in terms of their predicted effect on the viability of the target species. As this work progresses and more demographic and ecological data accumulate, it will be possible to come up with more realistic results and pragmatic management recommendations.

REFERENCES

Akçakaya, H.R. 2002. *Linking spatial data with population viability analysis*. Ramas GIS User Manual V.4 Applied Biomathematics. Setauket, New York.

Akçakaya, H.R and Atwood, J.L. 1997. A habitat-based metapopulation model of the California Gnatcatcher *Conservation Biology* 11:422-434

Baitello, J.B.; Pastote, J.A.; Aguiar, O.T.; Serio, F.C.; Silva, C.E.F. 1988. A vegetação arbórea do Parque Estadual do Morro do Diabo, Município de Teodoro Sampaio, Estado de São Paulo. *Acta Botanica Brasilica*, 1(2): 221-230.

CAMTRAKKER Inc. www.camtrakker.com

Cullen, L., Bodmer, R.E. and Valladares Padua, C. 2000. Effects of hunting in habitat fragments of the Atlantic forests, Brazil. *Biological Conservation* 95:49-56.

Crawshaw P.G., Mahler, J.K., Indrusiak, C., Cavalcanti, S.M.C., Leite, M.R.P.L., Silvius, K.M. 2004. Ecology and conservation of the jaguar (*Panthera onca*) in Iguacú National Park. In: Silvius, K.M., Bodmer, R.B. (eds). People in Nature: *Wildlife Conservation in South and Central America*. Pp 271-285, University of Columbia Press.

Foreman, D. and K. Daly. 2000. An ecological approach to wilderness area designation. *Wild Earth* 10(4):66-72.

Ivlev, V.S. 1961. *Experimental ecology of the feeding of fishes*. Yale Univ. Press, New Haven.

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

Karanth, U. and Nichols, J. 2002. *Monitoring Tigers and Their Prey A Manual for Researchers, Managers and Conservationists in Tropical Asia* 208 p. Centre for Wildlife Studies, Bangalore, India

Leite, M.R.P., Boulhosa, R.L.P. Galvão, F,. and Cullen, L. 2002. Ecology and Conservation of Jaguar on Atlantic Coastal Forest, Brazil. In: Medellin, R. A., C. Chetkiewicz, A. Rabinowitz, K. H. Redford, J. G. Robinson, E. Sanderson, and A. Taber. (eds). Pp. 45-56. Jaguars in the new millennium. *A status assessment, priority detection, and recommendations for the conservation of jaguars in the Americas*. Universidad Nacional Autonoma de Mexico/Wildlife Conservation Society.Mexico D. F.

Meffe, G.K. and C.R. Carroll. 1997. Genetics: Conservation of Diversity within Species. In, *Principles of Conservation Biology*. Sinauer Associates, Inc. Publishers, Sunderland, Massachusetts. Pp.161-179.

Newmark, W.D. 1995. Extinction of mammal populations in western North American national parks. *Conservation Biology* 9:512-526.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monograph* 62. 135pp.

Rabinowitz, A.R. and Nottingham, B.G. 1986. Ecology and behaviour of the jaguar (*Panthera onc*a) in Belize, Central America. *J. Zool., Lond*. 210:149-159.

Rexstad, E., and K.P. Burnham. 1991. *Users Guide for Interactive Program CAPTURE.* Colorado Cooperative Fish & Wildlife Research Unit, Colorado State University, Fort Collins, Colorado.

Sandell, M. 1989. The mating tatics and spacing patterns of solitary carnivores. *In: Carnivore behaviour, ecology and evolution*. Pp. 164-182. Chapman & Hall, London, United Kingdom.

Sanderson, E.W., Redford, K.H., Vedder, A., Coppolillo, P.B. and Ward, S.E. 2002. A conceptual model for conservation planning based on landscape species requeriments. *Landscape and Urban Planning* 58: 41-56.

Seidensticker, J. 1986. Large carnivores and the consequences of habitat insularization: ecology and conservation of tigers in Indonesia and Bangladesh. *In*: S.D. Miller and D.D. Everett (eds.). Pp 1-42 Cats of the world: biology, conservation and management. National Wildlife Federation, Washington D.C.

Schaller, G.B. and Crawshaw, P.G. 1980. Movement patterns of jaguar. *Biotropica* 12:161-168.

Schaller, G.B. 1983. Mammals and their biomass on a Brazilian ranch. *Arq. Zool.* Sao Paulo 31:1-36.

Shaffer, M. 1987. Minimum viable populations: Coping with uncertainty. *In*: M.E. Soulé (Ed.) Viable Populations for Conservation. Pp 69-86. Cambridge: Cambridge University Press.

Silver, S. C., Linde, E. T. O., Marsh, L. K., Maffei, L., Noss, A., Kelly, M J., Wallace, R. B., Gomez, 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):1-7.

Soulé, M., and R. Noss. 1998. Rewilding and biodiversity: complementary goals for continental conservation. [Online]. Available at: http://www.twp.org/aboutus/currprojects/rewilding/images/rewilding.pdf

Soulé, M. E., and J. Terborgh, editors. 1999. *Continental conservation: scientific foundations of regional reserve networks*. Island Press, Washington, D.C., . Wilson Bull. 111(1): 22-29.

Televilt GPS Radio Tracking.2003. www.televilt.se

Terborgh, J. 1998. The big things that run the world. *Conservation Biology*. 2:402-403.

Terborgh, J. 1999. *Requiem for Nature*. Island Press, Washington, D. C.