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Research Article

Identifying Important Forest Patches for the Long-term Persistence of the Endangered Golden-Headed Lion Tamarin (*Leontopithecus chrysomelas*)

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Abstract

As habitat for the golden-headed lion tamarin (GHLT; *Leontopithecus chrysomelas*) in Brazil's Atlantic forest becomes smaller and more fragmented, remaining large forest patches may be critical to the persistence of the species. The objectives of our study were to identify the forest patch size that could support a viable population of GHLTs under a range of risk scenarios and to locate patches meeting these size requirements. We found the self-sustaining minimum viable population (MVP) size of GHLTs using the simulation program Vortex under a baseline model and under several anthropogenic disturbance models. We multiplied the MVP size determined in each model scenario by low, medium, and high GHLT population densities to estimate a minimum area requirement. We then used a forest cover map derived through a supervised classification of 2004-2008 Landsat 5TM imagery to locate forest patches meeting the range of minimum area requirements. We found that the MVP size of GHLTs is 70-960 individuals, requiring a forest patch size of 700-18,113 ha depending on the risk level or scenario considered. We found one forest patch that could support a genetically viable, self-sustaining population of GHLTs under the highest level of risk. However, only one federally protected reserve known to currently support GHLTs exists within the range of the species while continuing deforestation, land conversion, and construction projects are real and major threats to the remaining GHLT habitat. Research into the quality and occupancy of the largest patches highlighted here as well as additional protection of habitat needs to be a priority for GHLT conservation.

Key Words: Atlantic forest, Golden-headed lion tamarin, Minimum area requirement, Minimum viable population (MVP), Population viability analysis (PVA)

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Introduction

The Atlantic forest is one of the world's hotspots for biodiversity, providing habitat for a disproportionately high number of species and facing severe deforestation at 92.5% loss of the region's original forest cover [1, 2]. Deforestation has been attributed to economic activities; 80% of Brazil's gross domestic product is generated in the Atlantic forest through intensive timber harvest, charcoal production, cattle ranching, and monoculture plantations [3, 4]. Because of the highly fragmented nature of forest patches within the Atlantic forest, the few remaining large forest patches may be especially important for the persistence and genetic stability of a variety of forest species [5-10]. Large fragments are more likely to have enough resources to maintain self-sustaining source populations that do not rely on immigrants for population persistence [11] whose individuals may then contribute to an entire regional population through dispersal and metapopulation dynamics [12, 13]. Such paired source-sink systems contribute positively to metapopulation size and persistence [14], and the larger patches, sometimes termed "key patches" [15], are thus critical to landscape planning. Locating large patches within the range of a species can help to prioritize locations for surveys, research, and habitat conservation.

Golden-headed lion tamarins (GHLTs; *Leotopithecus chrysomelas*) are one of many endemic and threatened species of the Atlantic forest. Large forest fragments are likely to be especially important for this endangered [16] arboreal primate that maintains large home ranges at relatively low population densities. Our objectives were to determine (1) a range of minimum area requirements for a self-sustaining, minimum viable population (MVP) of GHLTs under various risk scenarios and (2) the location of actual patches meeting these minimum area requirements throughout the species' range in Brazil. A number of other landscape characteristics such as functional connectivity between habitat patches [17-21], amount of edge [22], past land use [7], and habitat quality within patches [23] are important for species persistence. Incorporating these landscape characteristics is beyond the scope of this paper but will serve as the focus of future analyses. In this paper we propose a selective process by which key geographic areas can be quickly identified and used to direct species conservation efforts.

Fig. 1. (a) A juvenile golden-headed lion tamarin (GHLT). (b) GHLTs utilize primary, (c) secondary, and (d) shade cocoa forests as habitat. (photos taken by S. Zeigler, 2006)

Methods

Study Species

The last published estimate of GHLT population size, based on a 1991-1993 survey, was 6,000-15,500 individuals spanning a range of 19,462 km^2 [24]. However, a more recent survey suggests the possibility of a considerable population size and range reduction since then [25]. Forest cover in this region is characterized by highly deforested and fragmented seasonal semi-deciduous tropical rainforest in the west and more contiguous coastal evergreen tropical rainforest in the east. GHLTs use primary and secondary/regenerating forest as well as shade-cocoa plantations [26] below 500 m altitude [24] (Fig. 1). Based on a study in Una Biological Reserve, GHLTs form groups averaging five individuals with a dominant breeding female [27]. Territory size ranges between 0.36 km^2 [28] and 1.2 km^2 [26, 29, 30].

Determining Minimum Area Requirements

To calculate the minimum area requirements of the species, we began by determining the MVP size in the population viability analysis (PVA) program Vortex ver. 9.72 [31]. We define the MVP size as the smallest size at which the population is self-sustaining with a reproductive rate that exceeds mortality despite the potential effects of natural catastrophes and demographic, environmental, and genetic stochasticity, resulting in a persistent population that does not rely on immigration.

Baseline demographic parameters for the PVA model were calculated from field observations and from published literature on GHLTs (Appendix 1).

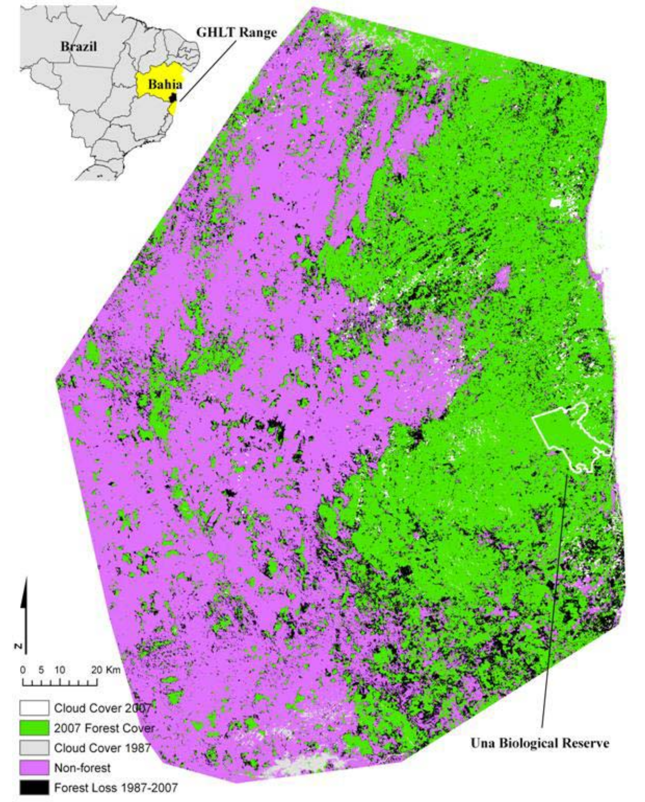

Fig. 2. Change in forest cover between 1987 and 2007 throughout the range of the golden-headed lion tamarin in Bahia, Brazil.

Field observations of the number of deaths, emigrations, immigrations, and births of GHLTs per year were made by B. E. Raboy as part of a long-term monitoring project of GHLTs in the Una Biological Reserve. Demographic rates used in this study were based on six habituated GHLT groups observed between 1995 and 2007 as part of this monitoring project. Two of the groups were followed for the full 12 years, one group was followed for 9 years, one group was followed for 7 years, and two groups were followed for 5 years. The average mortality rate was calculated for each sex and age class 0-1 years, 1-2 years, 2-3 years, 3-4 years, and adults. We did not differentiate mortality rates by sex for the 0-1 age class since the sex of infants was often unknown. Because the fate of individuals that disappeared was unknown, and given the high rate of mortality for individuals unable to successfully emigrate into a new group, we assumed that 75% of all disappearances were deaths except in the case of infants in the 0-1 year age class. All disappearances for infants were assumed to be deaths as individuals of this age class have never been seen emigrating. Thus, mortality for each age class was calculated as:

$$\text{Average mortality} = (N_{\text{deaths}} + 0.75 * N_{\text{disappearances}}) / N_{\text{total}}$$

We calculated the percentage of females breeding as:

$$\text{Percentage females breeding} = N_{\text{females that had offspring}} / N_{\text{total females}}$$

Finally, females are known to produce a total of one to four offspring per reproductive year based on one to two breeding cycles in a year. Thus, we calculated the frequency of litter sizes of one, two, three, or four offspring per female per reproductive year as:

$$\text{Frequency of litter size } i = N_{\text{litters of size } i} / N_{\text{total litters of all sizes}}$$

Here “litter” is used in the language of the Vortex model used to conduct PVA modeling and reflects the number of offspring produced per female per reproductive year, not the number of offspring produced in a single reproductive event. Lion tamarins give birth to singletons or twins one to two times a year.

Total variance in mortality, frequency of females breeding, and frequency of each litter size were calculated according to Kendall [32] while demographic and environmental variance was calculated according to Akcakaya [33]. These values were used to incorporate demographic and environmental stochasticity separately in PVA modeling.

To determine the MVP size, we kept all baseline parameters (Appendix 1) the same with the exception of initial population size (N_0) and carrying capacity (K). We assumed that N_0 was at K and systematically increased these two parameters from a starting population size of 5 until the population had a 98% probability of persistence for 100 years (Threshold 1). We were also interested in how large a population would need to be to retain 98% of its genetic diversity, what we define as a “genetically viable” population. Thus, we further increased population size until the population had both a 98% probability of persistence and maintained 98% of its genetic diversity for 100 years (Threshold 2). These thresholds have been used in previous modeling studies as the acceptable levels of risk for the species [34]. For both thresholds, population size was increased in multiples of five individuals to correspond to the average GHLT group size. As social animals, a stable and self-sustaining population of GHLTs is likely composed of several groups and would be a multiple of five assuming an average group size of five. Our models assumed that habitat quality and quantity did not change through time. We ultimately modeled the required size necessary for a single hypothetical population to persist with no immigration or emigration.

Population size was simulated for four scenarios under each threshold to determine the population size necessary for recovery from catastrophes under a number of different acceptable risk levels: (1) baseline with no catastrophes; (2) disease, 2% frequency with a 25% decrease in survival; (3) fire catastrophe, 2% frequency with a 50% reduction in survival; and (4) combination of both the fire and disease catastrophes. Fire and disease, as individual and combined threats, were modeled as catastrophes within Vortex where survival was reduced for both sexes across all age classes as specified during random catastrophe years and reproduction remained unaffected. Because this model follows a single hypothetical population and is not spatially explicit, catastrophes could impact any individual within the population. These particular catastrophes and the frequency and severity in which they affected the population were chosen because they have been cited in previous modeling studies as realistic threat levels for the species [34-36].

For each MVP size determined in the four PVA scenarios at the two thresholds (a total of eight population sizes), we multiplied the population size by published density estimates for GHLTs to determine a corresponding minimum area requirement. GHLTs have been observed at high (0.1 GHLT/ha), medium (0.067 GHLT/ha) and low (0.053 GHLT/ha) densities [34], likely reflecting differences in habitat type/quality (e.g., primary forest versus regenerating forest). The eight MVP sizes were multiplied by all three density estimates to determine a range of minimum area requirements due to uncertainty in density.

Analysis of the Landscape

To determine the location of patches meeting minimum area requirements, we conducted a supervised classification using the maximum likelihood algorithm [37] in ENVI ver. 4.3 on 30x30 m resolution Landsat 5 TM remotely sensed imagery. We performed the classification on two sets of the four overlapping Landsat scenes covering the GHLT range. In the first set, henceforth referred to as the “1987 mosaic,” Landsat TM images were captured in September 1986, August 1988, and June 1987. The second set, the “2007 mosaic”, consisted of Landsat TM images captured in June 2004, July 2007, August 2007, and August 2008. The four images for each time period were orthorectified to Landsat 7 ETM+ imagery and mosaicked together to form a single image. Pixels in each mosaic were classified as (1) forest, (2) non-forest, (3) clouds, (4) cloud shadows, and (5) water. GPS points for forest collected between 2005 and 2009 (Oliveira, unpublished data; Raboy, unpublished data) were used as training (2,146 points) and validation (2,144 points) data. A previous landscape classification by Laudau et al. [38] provided training (701 points) and validation (701 points) data for non-forest areas. Accuracy of our supervised classification was assessed with a confusion matrix [39], indicating an accuracy of 92.30% (kappa coefficient 0.80) for the 1987 mosaic and an accuracy of 93.50% (kappa coefficient 0.83) for the 2007 mosaic.

In ArcGIS ver. 9.3, areas of cloud cover were filled in using Landsat 5 TM imagery from May 1994 and June 1986 for the 1987 mosaic and from June 2004, January 2005, September 2006, and April 2007 for the 2007 mosaic. The 1987 and 2007 mosaics were then processed through the majority filter to remove noise, clipped based on the boundary of the GHLT range, and grouped into patches. The range boundary to the west is based on a minimum convex polygon created from all historical past published registries of the species [40] while the Atlantic Ocean serves as the principal range boundary to the east. The Rio de Contas and Rio Jequitinhonha rivers marked the northern and southern limits, respectively, of the species’ range [24]. The portions of forest patches that fell outside of these boundaries were not considered in our analyses.

Cloud cover and the presence of monoculture plantations, typically not used as habitat by GHLTs, within the area of study presented two potential problems that could not be removed for subsequent analyses. Monoculture plantations were not distinguished from the forest category in our classification because of the difficulties in reliably separating these classes in this region of Brazil [41]. However, according to a previous landscape classification, monoculture plantations represented less than 1% of the total ground cover within the GHLT range in 1995 [38] and should not greatly impact our analyses. Areas covered by clouds and their shadows were removed as much as possible with the alternate imagery described above; however, some areas were covered by clouds or shadows in both sets of images. Such areas, which covered 1.68% and 1.22% of the 1987 and 2007 mosaics, respectively, were not included in our analyses.

Using these processed 1987 and 2007 mosaics, we then identified forest patches meeting the minimum area requirement for each modeling scenario and GHLT density estimate. Because GHLTs are unlikely to use forest above 500 m, we also removed portions of forest patches that were above 500 m in ArcGIS using elevation data from the Shuttle Radar Topography Mission [42]. We then repeated our identification of patches meeting the minimum area requirements for each modeling scenario and GHLT density estimate.

We concluded our analyses by comparing the patches where we would expect to find GHLTs based on the modeling work presented here with the patches that are actually occupied by GHLTs. We overlaid 90 positive survey locations collected between 2005-2008 by the Conexão Mico Leão survey project [25, 43] over the 2007 mosaic. “Positive survey locations” included confirmed sightings of and vocalizations from GHLTs by field teams in playback studies as well as recent sightings by local residents with high forest knowledge [25]. Some survey locations did not directly align with a forest patch in our classification (37 points), and we assigned these points to the nearest patch. In the three instances where it was not clear which patch was closest, the survey location was not included in our analyses. Survey points were matched to patches on the landscape in order to determine the range of patch sizes occupied.

Results

Demographic Analysis

According to stochastic PVA analysis, at least 70 GHLTs are needed for a self-sustaining population with a 98% probability of persistence for the next 100 years if no catastrophes are included. MVP sizes of 90, 170, and 250 GHLTs are needed for a population that can persist despite disease, fire, and fire with disease catastrophes, respectively (Table 1). Based on these values, habitat patches as small as 700 ha (assuming baseline scenario and high population density) and as large as 4,717 ha (assuming fire with disease scenario and low population density) would be needed to support a self-sustaining GHLT population depending on the acceptable level of risk conservationists are willing to consider (Table 1**).**

Substantially higher population sizes are necessary to ensure that 98% of genetic heterozygosity is maintained over 100 years when various possible catastrophes are considered: 780 GHLTs (baseline), 810 GHLTs (disease), 920 GHLTs (fire), and 960 GHLTs (fire with disease; Table 1). These MVP sizes translate to habitat patches that are at least 7,800 ha (assuming baseline scenario and high population density) to 18,113 ha (assuming fire with disease scenario and low population density; Table 1).

Table 1. Minimum viable population (MVP) size and the corresponding minimum area requirement for the golden-headed lion tamarin (GHLT) under low (0.053 GHLT/ha), medium (0.067 GHLT/ha), and high (0.1 GHLT/ha) densities.

Scenario	**MVP size (# of GHLTs)**	**Minimum Area Requirement (ha)**			**$N_{t=100}$**	**r (sd)**	**Prob of Survival (%)**	**Genetic Diversity (%)**
		Low Density	Medium Density	High Density				
Threshold 1: 98% Probability of Survival								
Baseline	70	1,321	1,045	700	58	0.013 (0.085)	98.0	79.2
Disease	90	1,698	1,343	900	72	0.024 (0.091)	98.0	82.2
Fire	170	3,208	2,537	1,700	137	0.020 (0.107)	98.2	89.0
Disease with Fire	250	4,717	3,731	2,500	193	0.018 (0.114)	98.2	91.6
Threshold 2: 98% Probability of Survival and Maintenance of Genetic Diversity								
Baseline	780	14,717	11,642	7,800	779	0.051 (0.032)	100.0	98.0
Disease	810	15,283	12,090	8,100	785	0.043 (0.057)	100.0	98.0
Fire	920	17,358	13,731	9,200	834	0.038 (0.095)	100.0	98.0
Disease with Fire	960	18,113	14,328	9,600	837	0.026 (0.122)	100.0	98.0

Landscape Analysis

Between 1987 and 2007, forested area, the number of forest patches, and the average size of forest patches within the range of the GHLT decreased (Fig. 2; Table 2). In 1987, forest covered 1,111,657 ha of the GHLT range in 17,132 patches with a mean patch size of 71 ha. The amount of forest, number of patches, and mean patch size decreased by 2007 to 965,861 ha, 15,713 patches, and 61 ha, respectively. The net forest loss was 13% between 1987 and 2007 (Table 2). In addition, of the 15,713 forest patches within the GHLT range in 2007, only 778 of those patches were larger than the smallest published GHLT territory size (Table 2). Thus, only a fraction of the total available forest patches are likely large enough to support even a single GHLT group.

According to our PVA modeling, forest patches exist within the GHLT range that could support a population of GHLTs with a 98% probability of persisting for the next 100 years. In 1987, assuming medium GHLT density, 27 patches (baseline), 20 patches (disease), 7 patches (fire), and 5 patches (fire with disease) were large enough to support populations under the various risk scenarios (Table 2). Due to habitat loss and fragmentation over the next 20 years, the number of patches able to support the same population sizes in 2007 were 22 (baseline), 20 (disease), 9 (fire), and 6 (fire with disease; Table 2 ; Fig. 3a).

Though the largest patch in 1987 (872,502 ha) decreased in size by 2007 (741,973 ha), it still remained the largest patch in the GHLT range. However, the identity and location of many of the other large forest patches changed throughout the 20-year span of our landscape analysis. Of the top ten largest patches in 1987, four of these patches fragmented into patches that were smaller than the 1,045 ha needed to support a self-sustaining population at baseline conditions in 2007. Two of the ten largest patches in 1987 remained within the 10 largest patches in 2007, though these patches decreased in size between 1987 and 2007. Four of the 10 largest patches in 2007 had been connected to the largest patch in 1987.

Table 2. Forest cover and number of forest patches meeting the minimum area requirements under four catastrophe scenarios for the golden-headed lion tamarin (GHLT) assuming a medium density of 0.067 GHLT/ha. Numbers of patches are shown for 1987 and 2007 as well as for 2007 after all high altitude (> 500m) forest was removed.

Scenario	**Minimum Area Requirement (ha)**	**Number of Patches**		
		1987	2007	2007 (no high alt forest)
Total Forested Area	----------	1,111,657 ha	965,861 ha	880,179 ha
Total Number of Patches	----------	17,132	15,713	15,502
Mean Patch Size	----------	71 ha	61 ha	----------
Number of Patches Equal to or Larger than Smallest Published Territory Size	36	810	778	742
Threshold 1: 98% Probability of Survival				
Baseline	1,045	27	22	18
Disease	1,343	20	20	14
Fire	2,537	7	9	5
Disease with Fire	3,731	5	6	4
Threshold 2: 98% Probability of Survival and Maintenance of Genetic Diversity				
Baseline	11,642	2	2	2
Disease	12,090	2	2	2
Fire	13,731	1	2	1
Disease with Fire	14,328	1	1	1

Fewer patches were able to support a population that could also retain 98% of its genetic heterozygosity. In 1987, two patches were large enough to support a genetically viable population of GHLTs assuming medium GHLT density for the baseline and disease catastrophe scenarios while only one patch could support such a population under the fire and fire with disease catastrophe scenarios. These patches were very large (872,502 ha and 13,575 ha) and were located only in the eastern portion of the species' range. In 2007, there were two patches large enough to sustain a viable GHLT population and its genetic heterozygosity, assuming medium density under the baseline, disease, and fire catastrophe scenarios and one patch under the fire with disease scenario. The largest patch able to sustain a genetically viable population in 1987 (872,502 ha) was the same patch in 2007 (741,973 ha). However, the second patch able to sustain a genetically viable population in 1987 fragmented into smaller patches below the minimum area requirement while the second patch able to sustain a genetically viable population in 2007 (13,735 ha) had been part of the largest patch in 1987.

High elevation areas may limit the amount of area within a given forest patch that GHLTs can utilize. Previous studies cite that the altitudinal limit for the species is 500 m [24]. After removing forest cover above 500 m from our analysis, we found fewer patches with enough lowland forest to sustain populations of GHLTs with a 98% probability of persistence: 18 patches (baseline), 14 (disease), 5 (fire), 4 (fire with disease; Table 2; Fig. 3b). Two patches were able to support populations with 98% probability of survival and

98% genetic heterozygosity under the baseline and disease scenarios while one patch could support such a population under the fire and fire with disease scenarios (Table 2; Fig. 3b).

Discussion

Patch Size and Occupancy

According to positive survey locations of GHLTs, patch occupancy was not limited to patches meeting the minimum area requirements determined here. For the 21 occupied patches in the 2007 mosaic, 4 patches were larger than the baseline minimum area requirement of 1,045 ha, 11 patches were between 36 ha (the smallest published GHLT territory size) and 1,045 ha, and 6 patches were less than 36 ha. Small patches could have been occupied during these years for several reasons. In most of the surveys, patches were sampled one or two times, and occupancy is thus a snapshot of GHLT movement at that time. An individual GHLT may have been in a given location temporarily as it moved between or in and out of larger forest patches in search of additional resources. Patches may have been occupied by declining populations, and positive survey locations in smaller patches may represent extinction debt [44] or time lags between past land use and current species dynamics [7]. Finally, smaller fragments may be functionally connected with GHLTs moving between patches in search of resources, and the functional size of patches may be larger than the structural size. Connectivity can be a particularly important attribute of a landscape for species survival [45], and assessing the implication of varying levels of inter-patch connectivity for GHLTs represents the authors' next steps in identifying geographic regions of the GHLT's landscape for targeted conservation action.

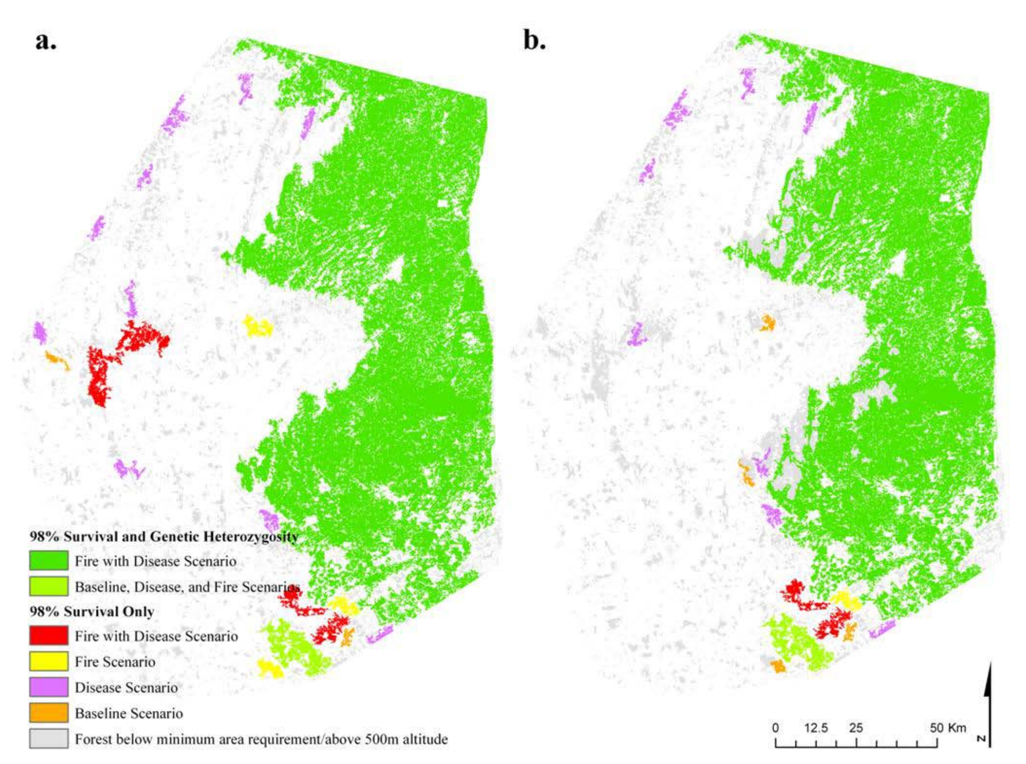

Fig. 3. Key forest patches meeting the minimum area requirements that could support a population of golden-headed lion tamarins at medium density with a 98% probability of survival for 100 years and 98% of its original genetic heterozygosity at baseline with no catastrophes and with a risk of disease, fire, and disease with fire. A. depicts key patches considering all forest cover within the patch while B. depicts key patches after all forest above 500m was removed from patches.

Deforestation and Conservation Implications

Like other studies identifying important forest patches for species survival in the Atlantic forest [9], we found only one to two forest patches (depending on the risk scenario considered) that are theoretically large enough to support a genetically viable, self-sustaining population of GHLTs for the next 100 years. However, this should not imply that the species is safe from continuing population decline or extinction. Forest cover in this region is changing quickly. Our analysis indicates a net forest loss of 13% in the GHLT range between 1987 and 2007, or 0.65% loss per year if constant deforestation rate is assumed. This is relatively congruent with the deforestation rate in the state of Bahia as a whole. Between 2000 and 2005, 2.2% (or 0.44% per year) was lost within the state [46]. The Bahia biogeographical sub-region [47] is the second most well-preserved sub-region in the Atlantic Forest with 17.7% of the original forest cover remaining [48]. It is conceivable that deforestation pressure in the more well-preserved sub-regions like Bahia will increase as what little forest remains in sub-regions like Sao Francisco (4.7% remaining forest cover) and Interior Forest (7.1% remaining forest cover) is completely lost [48]. In addition, a large percentage of available forest cover for use by GHLTs is currently in the form of shade-cocoa plantations, covering 18% of the total range of the species in 1995 [38]. These plantations are becoming threatened as the low price of cocoa and fungal epidemics infecting cacao trees and fruit make it more profitable for land-owners to convert their cocoa agroforestry systems to cattle pastures and other agricultural systems of low biodiversity value [49]. Such land conversion would drastically reduce the amount of available habitat for GHLTs.

Though one to two forest patches in the GHLT range could theoretically support a self-sustaining, genetically viable population of GHLTs despite catastrophes, there is only one federally protected reserve known to currently support GHLTs where continuing deforestation is unlikely. A previous modeling study found that this reserve, Una Biological Reserve (Fig. 2), is large enough to safeguard the species *if* the park is able to hold a high or medium density of GHLTs and forest regeneration continues to increase the park's carrying capacity as projected. However, at lower densities or when K did not increase, genetic diversity fell below the 98% threshold [34]. Fire threat was also not included in the model but may be a real and present threat given the level of farming activity bordering the reserve. Given that some of the lowest densities were observed for GHLTs within the reserve in some years [26], expansion of the size of the reserve is critical.

The distribution of forest patches throughout the GHLT range is also important. A genetic study of four subpopulations of a closely related species, the golden-lion tamarin (*Leontopithecus rosalia*), showed significant differences in the total number of alleles, heterozygosity, and allelic frequency among subpopulations [50]. The smallest and largest genetic differences between populations corresponded to the smallest and largest linear distances between populations [50]. Although a genetic study has yet to be completed for GHLTs, a behavioral study comparing subpopulations in the eastern and western portions of their range found differences in the foraging ecology of the species, suggesting adaptation to local environments [51]. It is possible that "western" GHLTs, found in semi-deciduous tropical rainforest, are genetically distinct from individuals found in coastal evergreen tropical rainforest in the east. Thus, it may be important that large populations are protected in both the eastern and western portions of the GHLT range to ensure the conservation of the species and its genetic diversity. Currently, no patches large enough to maintain a population of GHLTs with 98% genetic heterozygosity are found in the western portion of the species' range. In addition, habitat loss and fragmentation were considerably higher in the western portion of the range between 1987 and 2007, and, again, the only federally protected area known to currently support a population of GHLTs lies in the eastern portion of the species' range. Raboy et al [25] confirm that many local extinctions have already occurred in the west within the last few decades and many more are imminent.

Finally, in addition to continuing deforestation threats, PETROBRAS, a Brazilian energy company, is investing in a multimillion dollar project to construct the Southeast Northeast Interconnection Gas Pipeline (GASENE). This natural gas pipeline will run 1,387 km from Rio de Janeiro to Catu along the Atlantic coast [52-54]. A section of this pipeline is slated to run through the GHLT range (Fig. 4), fragmenting the largest forest patch in half through the entire length of the patch. The short-term impacts of construction and the long-term impacts of the pipeline itself on GHLT metapopulation survival and movement are currently unknown. However, the internal fragmentation caused by this development project will likely impact the species throughout the construction zone [55].

Fig. 4. Early construction of the PETROBRAS natural gas pipeline slated to run through the range of the golden-headed lion tamarin in Bahia, Brazil. (photos taken by S. Zeigler, 2006)

In conclusion, two large forest patches exist that could theoretically support a genetically viable, self-sustaining population of GHLTs able to recover from moderate catastrophes while one patch could support such a population under more severe catastrophes. Only one federally protected reserve known to currently support a population of GHLTs exists within the range of the species, while continuing deforestation, land conversion, and construction projects such as the PETROBRAS pipeline are real and major threats to the remaining GHLT habitat patches. Research into the quality and occupancy of the largest patches highlighted here as well as additional protection of habitat needs to be a high priority for the conservation of the GHLT.

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Literature Cited

[1] Shi, H., Singh, A., Kant, S., Zhu, Z. and Waller, E. 2005. Integrating habitat status, human population pressure, and protection status into biodiversity conservation priority setting. *Conservation Biology* 19: 1273-1285.

[2] Myers, N., Mittermeier, R., Mittermeier, C., Fonseca, G. d. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853-858.

[3] Morellato, L. and Haddad, C. 2000. Introduction: the Brazilian Atlantic forest. *Biotropica* 32: 786-792.

[4] Pinto, L. P. and Wey de Brito, M. C. 2003. Dynamics of biodiversity loss in the Brazilian Atlantic Forest: An Introduction. In: *The Atlantic Forest of South America: biodiversity status, trends, and outlook.* Galindo-Leal, C. and de Gusmao Camara, I. (Eds.), 27-30. Center for Applied Biodiversity Science and Island Press, Washington, DC.

[5] Chiarello, A. 1999. Effects of fragmentation of the Atlantic forest on mammal communities in south-eastern Brazil. *Biological Conservation* 89: 71-82.

[6] Vieira, M. V., Olifiers, N., Delciellos, A. C., Antunes, V. Z., Bernardo, L. R., Grelle, C. E. V. and Cerqueira, R. 2009. Land use vs. forest fragment size and isolation as determinants of small mammal composition and richness in Atlantic Forest remnants. *Biological Conservation* 142: 1191-1200.

[7] Metzger, J. P., Martensen, A. C., Dixo, M., Bernacci, L. C., Ribeiro, M. C., Teixeira, A. M. G. and Pardini, R. 2009. Time-lag in biological reponses to landscape changes in a highly dynamic Atlantic forest region. *Biological Conservation* 142: 1166-1177.

[8] Chiarello, A. G. and de Melo, F. R. 2001. Primate population densities and sizes in Atlantic forest remnants of Northern Espirito Santo, Brazil. *International Journal of Primatology* 22: 379-395.

[9] Brito, D. and Fernandez, F. A. S. 2002. Patch relative importance to metapopulation viability: the neotropical marsupial *Micoureus demerarae* as a case study. *Animal Conservation* 5: 45-51.

[10]Brito, D. and Grelle, C. E. V. 2006. Estimating minimum area of suitable habitat and viable population size for the northern muriqui (Brachyteles hypoxanthus). *Biodiversity and Conservation* 15: 4197-4210.

[11]Pulliam, H. 1988. Sources, sinks, and population regulation. *American Naturalist* 132: 652-661.

[12]Radford, J. Q. and Bennett, A. F. 2004. Thresholds in landscape parameters: occurrence of the white-browed treecreeper Climacteris affinis in Victoria, Australia. *Biological Conservation* 117: 375-391.

[13]Hanski, I. 1991. Metapopulation dynamics: brief history and conceptual domain. *Biological Journal of the Linnean Society* 42: 3-16.

[14]Howe, R., Davis, G. and Mosca, V. 1991. The demographic significance of sink populations. *Biological Conservation* 57: 239-255.

[15]Verboom, J., Foppen, R., Chardon, P., Opdam, P. and Luttikhuizen, P. 2001. Introducing the key patch approach for habitat networks with persistent populations: An example for marshland birds. *Biological Conservation* 100: 89-101.

[16]IUCN. 2009. IUCN Red List of Threatened Species version 2009.2. IUCN, Gland, Switzerland.

[17]Fahrig, L. and Merriam, G. 1985. Habitat patch connectivity and population survival. *Ecology* 66: 1762-1768.

[18]Anzures-Dadda, A. and Manson, R. H. 2007. Patch- and landscape-scale effects on howler monkey distribution and abundance in rainforest fragments. *Animal Conservation* 10: 69-76.

[19]Groom, M. 1998. Allee effects limit population viability of an annual plant. *The American Naturalist* 151: 487-496.

[20]Root, K. V. 1998. Evaluating the effects of habitat quality, connectivity, and catastrophes on a threatened species. *Ecological Applications* 8: 854-865.

[21]Fagan, W., Unmack, P., Burgess, C. and Minckley, W. 2002. Rarity, fragmentation, and extinction risk in desert fishes. *Ecology* 83: 3250-3256.

[22]Lopes, A. V., Girao, L. C., Santos, B. A., Peres, C. A. and Tabarelli, M. 2009. Long-term erosion of tree reproductive trait diversity in edge-dominated Atlantic forest fragments. *Biological Conservation* 142: 1154-1165.

[23]Holmes, R. and Sherry, T. 2001. Thirty-year bird population trends in an unfragmented temperate deciduous frest: Importance of habitat change. *The Auk* 118: 589-609.

[24]Pinto, L. and Rylands, A. 1997. Geographic distribution of the golden-headed lion tamarin. Leontopithecus chrysomelas: Implications for its management and conservation. *Folia Primatological* 68: 161-180.

[25]Raboy, B., Neves, L., Zeigler, S., Saraiva, N., Cardoso, N., Santos, G., Ballou, J. and Leimgruber, P. In press. Strength of habitat and landscape metrics in predicting golden-headed lion tamarin presence or absence in forest patches. *Biotropica*

[26]Raboy, B. and Dietz, J. 2004. Diet, foraging, and the use of space in wild golden-headed lion tamarins. *American Journal of Primatology* 63: 1-15.

[27]Raboy, B. E. 2002. The ecology and behavior of wild golden-headed lion tamarins (*Leontopithecus chrysomelas*). University of Maryland, College Park.

[28]Rylands, A. 1989. Sympatric Brazilian callitrichids: the black tufted-ear marmoset, *Callithrix kuhli*, and the golden-headed lion tamarin, *Leontopithecus chrysomelas*. *Journal of Human Evolution* 18: 679-695.

[29]Dietz, J., de Sousa, S. and Billerbeck, R. 1996. Population dynamics of golden-headed lion tamarins in Una Reserve, Brazil. *Dodo Journal of Wildlife Preservation Trusts* 32: 115-122.

[30]Raboy, B. E., Christman, M. C. and Dietz, J. N. 2004. The use of degraded and shade cocoa forests by endangered golden-headed lion tamarins *Leontopithecus chrysomelas*. *Oryx* 38: 75-83.

[31]Lacy, R. 2000. Structure of the VORTEX simulation model for population viability analysis. *Ecological Bulletins* 48: 191-203.

[32]Kendall, B. E. 1998. Estimating the magnitude of environmental stochasticity in survivorship data. . *Ecological Applications* 8: 184-193.

[33]Akcakaya, H. R. 2002. Estimating the variance of survival rates and fecundities. *Animal Conservation* 5: 333-336.

[34]Holst, B., Medici, E. P., Marino-Filho, O. J., Kleiman, D., Leus, K., Pissinatti, A., Vivekananda, G., Ballou, J. D., Traylor-Holzer, K., Raboy, B., Passos, F., Vleeschouwer, K. and Montenegro, M. M. 2006. Lion Tamarin Population and Habitat Viability Assessment Workshop 2005, Final Report. IUCN/SSC Conservation Breeding Specialist Group, Apple Valley, MN.

[35]Ballou, J., Lacy, R. C., Kleiman, K., Rylands, A. and Ellis, S. 1998. Leontopithecus II: The second population and habitat viability assessment for lion tamarins: Final report. Conservation Breeding Specialist Group (SSC/IUCN), Apple Valley, MN.

[36]Seal, U. S., Ballou, J. and Padua, C. V. 1990. Leontopithecus: Population viability analysis workshop report. Captive Breeding Specialist Group (SSC/IUCN), Apple Valley, MN.

[37]de Carvalho, L., Clevers, J., Skidmore, A. and de Jong, S. 2004. Selection of imagery data and classifiers for mapping Brazilian semideciduous Atlantic forests. *International Journal of Applied Earth Observations and Geoinformatics* 5: 173-186.

[38]Landau, E. C., Hirsch, A. and Musinsky, J. 2003. Cobertura Vegetal e Uso do Solo do Sul da Bahia-Brasil. In: *Corredor de Biodiversidade da Mata Atlãntica do Sul da Bahia.* Prado, P. I., Landau, E. C., Moura, R. T., Pinto, L. P. S., Fonesca, G. A. B. and Alger, K. (Eds.), IESB/DI/CABS/UFMF/UNICAMP, Publicacão em CD-ROM, Ilhéus, Brazil.

[39]Foody, G. M. 2002. Status of landcover classification accuracy assessment. *Remote Sensing of the Environment* 80: 185-201.

[40]Prado, P. I., Landau, E. C., Moura, R. T., Pinto, L. P. S., Fonesca, G. A. B. and Alger, K. (editor^editors). 2003. *Corredor de Biodiversidade Mata Atlantica Sul da Bahia*. IESB/CI/CABS/UFMG/UNICAMP,

[41]Lawrence, W., Saatchi, S., Defries, R., Dietz, J., Rice, R., Dietz, L., de Araujo, M. and Alger, K. 1995. Utilization of SAR and optical remote sensing data for habitat conservation in the tropical forest of Brazil. Geoscience and Remote Sensing Symposium, Firenze, Italy.

[42]Farr, T. G., Rosen, P. A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D. and Alsdorf, D. 2007. The Shuttle Radar Topography Mission. *Reviews of Geophysics* 45:

[43]Neves, L. G. 2008. Distribuicao geografica e conservacao de Callithrix kuhlii no sul da Bahia, Brasil. Universidade estadual de Santa Cruz-UESC, Ilheus/Itabuna, Brazil.

[44]Tilman, D., May, R. M., Lehman, C. L. and Nowak, M. A. 1994. Habitat destruction and the extinction debt. *Nature* 371: 65-66.

[45]Arroyo-Rodriguez, V. and Mandujano, S. 2009. Conceptualization and measurement of habitat fragmentation from the primates' perspective. *International Journal of Primatology* 30: 497-514.

[46]Fundacao SOS Mata Atlantica and INPE. 2008. Atlas dos remanescentes florestais da Mata Atlantica periodo 2000-2005 in Fundacao SOS Mata Atlantica and Instituto Nacional de Pesquisas Espaciais, editors, Sao Paulo.

[47]Silva, J. M. C. and Casteleti, C. H. M. 2003. Status of the biodiversity of the Atlantic Forest of Brazil. In: *The Atlantic Forest of South America: biodiversity status, trends, and outlook.* Galindo-Leal, C. and de Gusmao Camara, I. (Eds.), 27-30. Center for Applied Biodiversity Science and Island Press, Washington, DC.

[48]Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J. and Hirota, M. M. 2009. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation* 142: 1141-1153.

[49]Schroth, G. and Harvey, C. A. 2007. Biodiversity conservation in cocoa production landscapes: an overview. *Biodiversity Conservation* 16: 2237-2244.

[50]Grativol, A. D., Ballou, J. D. and Fleischer, R. C. 2001. Microsatellite variation within and among recently fragmented populations of the golden lion tamarin (Leontopithicus rosalia). *Conservation Genetics* 2: 1-9.

[51]Guidorizzi, C. E. 2008. Ecology and behavior of the golden-headed lion tamarin (Leontopithecus chrysomelas) in a mesophytic forest in southern Bahia, Brazil. Final Report for the Rufford Small Grants Foundation.

[52]Tubb, R. 2006. 2006 International Pipeline Construction Report. *Pipeline and Gas Journal* 233: 22-25.

[53]PETROBRAS. 2006. GASENE Project Financing. PETROBRAS, Rio de Janeiro.

[54]Piquet, R. and Miranda, E. 2009. A indústria de gás no Brasil: incertezas, implicações territoriais e perspectivas. *Novos Cadernos NAEA* 12: 51-66.

[55]Goosem, M. 2003. Internal fragmentation: The effects of roads. highways, and powerline clearings on movements and mortality of rainforest vertebrates. In: *Tropical forest remnants: Ecology, managements, and conservation of fragmented communities.* Laurance, W. F. and Bierregaard, R. O. (Eds.), University of Chicago Press, Chicago.

Appendix 1. Demographic parameters used in Vortex ver. 9.72 to model the minimum viable population size for golden-headed lion tamarins.

Parameter	Definition	Baseline Value	
Species Description			
Inbreeding Depression[1]	Considers reduction in first-year survival for inbred individuals	yes	
Number of Lethal Equivalents[1]	Average impact of inbreeding on first-year survival	4.07	
Dispersal		No dispersal, hypothetical single population	
Reproductive System and Rates			
Reproductive System[2]	Indicates whether species is monogamous or polygynous	Long-term monogamous	
Age First Offspring (female)[2]	Age at which females begin breeding	4 years	
Age First Offspring (male)[2]	Age at which males begin breeding	4 years	
Max Age Reproduction[2]	Age at which individuals cease producing offspring	16 years	
Max # Progeny[3]	Largest number of offspring a single female can produce in a given year	4 offspring	
1 offspring		33.3%	
2 offspring		45.5%	
3 offspring		4.5%	
4 offspring		16.7%	
Sex Ratio at Birth[2]	Average percentage of newborn males born	50% males	
% Adult Females Breeding[3]	Mean percentage of females that breed in a given year	82.9%	
% Males in Breeding Pool[2]	Mean percentage of males that breed in a given year	100%	
Mortality			
Mortality Rates[3] (environmental variation)	Mean mortality rate for each age class in a given year	Males (EV[4])	Females (EV[4])
0-1 year old		35.0%(0%)	35.0% (0%)
1-2 years old		13.9 (0)	14.8 (13.0)
2-3 years old		4.0 (3.0)	26.5 (0)
3-4 years old		5.4 (0)	28.1 (12.1)
> 4 years old		16.2 1.6)	13.3 (0)

[1] J. Ballou, personal communication.

[2] Holst et al. 2006.

[3] Raboy, B., unpublished data. Data based on observations of 6 GHLT groups (12 years). See Methods for how these rates were calculated from raw demographic data.

[4] Value of 0 indicates that all variation observed could be accounted for by demographic variance, which is automatically incorporated in Vortex.