POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA) FOR THE MURIQUI
(*Brachyteles arachnoides*)

Belo Horizonte, Brazil
23 - 26 May 1998

Report

Sponsored by:
The Margot Marsh Biodiversity Foundation

A Collaborative Workshop with:

Fundação Biodiversitas
IBAMA
Conservation International - Brazil

and

The Primate Specialist Group (SSC/IUCN)
The Conservation Breeding Specialist Group (SSC/IUCN)

A contribution of the IUCN/SSC Conservation Breeding Specialist Group in collaboration with the Fundação Biodiversitas, Conservation International – Brazil, IBAMA, and the Primate Specialist Group (SSC/IUCN).

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POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA)
FOR THE MURIQUI
(*Brachyteles arachnoides*)
Report

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Executive Summary and Recommendations

The muriqui is one of the world's greatest country-specific flagship species. It is comparable to the giant panda of China, the bonobo and the okapi in the Congo, the platypus and koala in Australia and the birds of paradise of New Guinea. The muriqui is the largest mammal endemic to Brazil, one of two primate genera endemic to the country and the largest non-human primate of the Americas. The two taxa in the genus *Brachyteles* are among the 35 most critically endangered primates on earth. Along with the lion tamarins, this species was primarily responsible in the late 1970s and early 1980s for putting the until then overlooked Atlantic forest region of Brazil at the top of the global priority list for biodiversity conservation, to the point that it is now considered one of the top five threatened biodiversity hotspots on Earth. Indeed, early work on the muriqui (and the lion tamarins), basic research, conservation efforts and public awareness campaigns are a classic example of use of a flagship primate to stimulate major international activity on behalf of a globally important eco-region.

In spite of this past success and the great future potential that this genus has for conservation in Brazil, it remains relatively unrealized. Indeed, in recent years, the main focus of muriqui conservation has been on research in Caratinga and a few other areas (which has served to further emphasize the uniqueness of the genus *Brachyteles*), with relatively little use nationally and even less internationally, of the muriquis as symbols for conservation efforts.

Recognizing the importance of the muriqui to conservation in Brazil, Fundação Biodiversitas, Conservation International - Brazil and Ibama, in collaboration with the Primate Specialist Group and the Conservation Breeding Specialist Group (SSC/IUCN), hosted a Population and Habitat Viability Assessment (PHVA) workshop 23-26 May 1998 in Belo Horizonte, Brazil. The goal of the workshop was to produce a collaborative and systematic conservation assessment for the muriqui.

Participants included representatives from Ibama, the Primate Center in Rio, local universities, Conservation International, FBCN, Fundação Biodiversitas, Instituto de Pesquisas Ecologicas, the World Wildlife Fund, Museu de Biologia – Espírito Santo, the Instituto de Floresta de Minas Gerais, and the Primate and Conservation Breeding Specialist Groups SSC/IUCN. After presentations on the current status and management of the muriqui, participants generated a list of problems to be addressed at the workshop (see section 1). Participants then grouped the problems into four working group themes: Distribution and Status; Population and Habitat Management; Social, Political and Economic Impacts on the muriqui; and Species Biology and Modeling. The recommendations from each working group follow.

Overall, the participants agreed that fundamental to realizing the muriqui's potential as a flagship species for the Atlantic rainforest is the establishment of an international management committee for the muriqui, similar to those currently in place for the four lion tamarin species and the two endangered Capuchan monkeys. These committees have been quite successful and have established a number of important precedents for collaboration in the conservation of endangered endemic species of Brazil.

We also believe that a major survey is a priority and a thorough understanding of the distribution and status of all remaining populations of the muriqui is fundamental to any long-term conservation efforts on their behalf. Continuation of the long-term research on the Caratinga muriquis will provide a critical comparative framework for evaluating other muriqui populations.

Distribution and Status Working Group

Distribuição e Status das Populações Remanescentes de *Brachyteles arachnoides*

- O grupo considera prioritária a implementação de um amplo programa de "survey" para mapear a situação atual de *Brachyteles*, identificando as áreas onde a espécie ainda ocorre e estimando, quando possível, o tamanho das populações.
- Para o desenvolvimento do censo será necessário a organização de um grupo de pesquisadores (comitê), com representantes dos estados onde ocorre *Brachyteles,* que deverá estabelecer metodologias padronizadas para o "survey", incluindo entrevistas, censos e diagnóstico de habitat.
- As áreas consideradas prioritárias para o "survey" deverão ser aquelas mais fragmentadas e isoladas, que se concentram nos estados de BA, MG e ES.

Implement an ample survey program to map the current status of *Brachyteles*, identifying the areas where the species still occurs and estimating, when possible, the size of the populations.

To develop the census it will be necessary to organize a group of resesarchers (the committee) with representations from the states where *Brachyteles* occurs. The committee should establish systematic methods for the census, including interviews and habitat evaluation.

The areas considered to be priorities for the survey should be those most fragmented and isolated, which are concentrated in the states of Bahia, Minas Gerais, and Espereto Santos.

Habitat and Population Management Working Group Recommendations

Priority areas were recommended for each of the following activities:

- If translocation of animals is done, young females at reproductive age should be captured and translocated from small areas with high density to large well protected areas with low population densities. Translocation of entire groups is not recommended.

- Priority sites for environmental education should be selected based on the following criteria: available logistics/accessibility to area; presence of local NGOs; pre-disposition of land owner (in case of private areas); and the degree of threat.

- Before starting any ecotourism initiative a viability study should be carried out for the proposed site.

- Increase habitat available for the muriqui:
    a) private lands = natural regeneration and reforestation should be considered to increase core areas, and the creation of corridors when there is a possibility to connect isolated patches of forest.
    b) protected areas = recuperation of habitat should be carried out when appropriate.

- An attempt should be made to create private reserves (RPPNs) where private areas are identified as extremely important for the conservation of the species.

<u>Social, Economic and Political Impacts</u>

Impactos sociais, economicos e politicos nas populacoes de *Brachyteles arachnoides*

- Regulamentar a extracao do palmito e providenciar fontes de proteina animal para as populacoes locais das comunidades de entorno. Providenciar desta forma fontes alternativas de alimento, buscando minimizar a caca de muriquis selvagens.

- Estabelecer oficialmente uma organizacao nao governamental local com intuito de coordenar as atividades relacionadas a conservacao do muriqui na regiao do Parque Estadual de Carlos Botelho, em primeira instancia.

- Oficializar uma rede de relacoes de pessoas locais interessadas na preservacao do meio ambiente, promovendo desta froma um maior envolvimento dos diferentes setores da comunidade.

Regulate the extraction of palmito and provide sources of animal protein fro the local human population in the surrounding communities. Provide alternative food sources so that hunting of muriquis is minimized.

Establish a local NGO to coordinate the activities related to the conservation of muriquis in the region of Carlos Botelho State Park.

Provide official status for groups of local people interested in environmental preservation to promote greater involvement by different sectors of the community.

<u>Species Biology and Modeling Working Group Recommendations</u>

1. Maintain and utilize the long-term data from the muriquis at the Estacao Biologica de Caratinga:

    a) Identify the criteria necessary to evaluate any future problems with this population that signal the need for rapid management responses.

b) Extrapolate from the Caratinga database to evaluate other muriqui populations as census results on the sizes, age and sex structures of other populations become available. These comparisons will be used to determine which populations are at the greatest risk of extinction.

2. For the Captive population at the Centro de Primatologia de Rio de Janeiro:

a) We anticipate that the primary role of the CPRJ for the muriqui will continue to be one of receiving confiscated individuals. We do not, at this point, envision the development of an extensive captive breeding program to be an immediate priority for the species.

b) To improve infant survivorship, we recommend that additional muriqui enclosures are constructed to accommodate the growing population. Increasing the housing possibilities at the CPRJ will reduce density pressures that may be interfering with infant survivorship.

2. Increase information on the demographic status of other muriqui populations:

a) Work with the census and management groups to maintain an updated data base on the size, composition, and density of other muriqui populations.

b) Stimulate the collection and maintenance of long-term demographic data on other muriqui populations. In particular, populations such as those at the Carlos Botelho-Intervales areas will provide critical comparative perspectives on muriquis living under more "natural" conditions than those at Caratinga.

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Report

Section 1
Introduction

Introduction

Workshop Invitation

7th May 1998

Dear colleague:

The IUCN/SSC Conservation Breeding Specialist Group (CBSG), in collaboration with Conservation International, the Fundação Biodiversitas and the Brazilian Institute for the Environment (Ibama), is organizing a Population and Habitat Viability Assessment Workshop for the Endangered Muriqui, *Brachyteles arachnoides*. The workshop is being sponsored by the Margot Marsh Biodiversity Foundation. It will be held from the 23rd to the 26th May 1998, at the Hotel Grandville Del Rey, Praça Afonso Arinos 60, Belo Horizonte, Minas Gerais, Tel: 031 273 2211, Fax: 031 273 1804.

The Organizing Committee is pleased to invite you to participate in this event. The aims and scope of the Workshop are attached, as is the preliminary agenda for the meeting. Please let us know if the agenda is appropriate - it is only provisional and can be changed.

We will be able to book hotel accomodation at the Hotel Del Rey if you would kindly let us (Ilmar Santos) know the dates of arrival and departure.

We look forward to hearing from you at your earliest convenience.

Yours sincerely,

Ilmar B. Santos
For the Organizing Committee

Please reply to:

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Population and Habitat Viability Assessment Workshop for the Endangered Muriqui, *Brachyteles arachnoides* - Belo Horizonte, 23rd-26th May 1998

PHVA Workshops on endangered species have provided invaluable opportunities for participants representing a wide variety of scientific, conservation, and governmental interests to convene to exchange knowledge, perspectives, and ideas for conserving their target species. We anticipate that the Muriqui PHVA Workshop will create a similarly stimulating and productive opportunity, and result in a compilation of available facts and systematic recommendations that will help ensure the survival of the largest endemic primate in the Americas. Indeed, considering that the precarious status of muriquis has been acknowledged for more than 20 years, a Workshop on its behalf is long overdue. Past difficulties associated with scheduling conflicts among the principle participants have now been overcome, and the baseline behavioral and life history data needed for the population viability simulations have now been accumulated and analyzed in a preliminary form (Strier, 1996, *Primate Conservation 1993-94*). Our recent analyses of differences betweeen northern and southern muriqui population distributions among protected and private forests (Strier and Fonseca, In press, *Primate Conservation*) further emphasizes the urgency for developing informed conservation strategies that are sensitive to local and regional conditions.

The specific goals for this Workshop are straightforward and achievable. Some of these are highlighted below:

- We will compile, distribute, and discuss existing knowledge of muriqui populations and results from problem-oriented field studies and captive breeding efforts to enhance our understanding of muriquis and their conservation status. One component of this objective is to increase access to information currently available in the scientific literature; another is to identify gaps in our knowledge about muriquis that need to be filled.
- We will merge population viability analyses with data on muriqui behavioral ecology and information about local habitat conditions to develop specific guidelines for the improved protection of this genus. Our PVA will use as its starting point a recently published VORTEX analysis (Strier, 1996, *Primate Conservation 1993-94*), supplemented with more recent mortality data from this population. We will also evaluate how well, if at all, these simulations derived from one population can be extrapolated to others, and what variables provide the most reliable indicators for assessing populations at the greatest risk.
- We will identify habitats that require special protection and management, and populations where active management might be justified. The advantages and risks of forest regeneration programs or muriqui translocations are examples of the kinds of possible management priorities that will be considered.
- We will develop research and conservation priorities for the genus, including identifying populations that merit special consideration for their scientific, educational, and economic (via eco-tourism) value, and establishing guidelines to ensure coordination among these various activities at such sites. Some muriqui populations, such as the one at the Estação Biológica de Caratinga, are well-known and easily accessible, and continue to serve as target sites for increasing conservation education awareness through visits by local school groups, documentary film crews and journalists, and international tourists.

Diverting some of the economic benefits of these visits may help increase conservation commitments by the landowners at this site. Identifying other muriqui populations, where comparable access for educational and tourism groups could be developed, that would stimulate similarly effective local conservation activities.

We will consider the role of the captive breeding program for muriquis at the Centro de Primatologia de Rio de Janeiro. If appropriate, we will establish priorities and recommendations for the future of muriquis born in this facility.

On the first day of the workshop, participants generated a list of problems and needs associated with conserving the muriqui. This list was used to select working groups for discussion and development of action priorities by the workshop participants for the remainder of the workshop. Participants self-selected working groups, and the recommendations from each working group are documented in this report. Participants in the workshop are listed in Appendix II.

Problem Statements:
1. priorizar acôes (prioritize the actions recommendations)
2. maximize the use of existing knowledge before generating new knowledge
3. funding (for all of the above)
4. charting human harvest of the muriqui
5. carrying capacity
6. Distribuicao (Distribution of the murqui populations)
7. population studies in new areas
8. exhaustive survey for populations
9. how many muriqui are left and where
10. What is the human impact on habitat (positive or negative)?
11. Industrial or commercial impacts on muriqui habitats (e.g. coffee, timber, cocoa)?
12. information on sex ratio of different populations
13. census data
14. reintroduction of populations into existing habitat
15. Catalog information on the vegetation of the forest habitats
16. Identificar as àrvores comidas peids M. (identify food plants of the muriqui)
17. identify locations for potential muriqui reintroduction
18. improve knowledge of habitat quality on forest fragments
19. translocation
20. conservation of buffer zones
21. Habitat quality (knowledge of habitat in the south - census and distribution - quality of habitat)
22. Find people to undertake conservation actions
23. Need NGO to link muriqui conservation + human side
24. need socio-economic information on communities and alternative socioeconomic activities
25. assist landowners with muriquis
26. Educacao ambiental junto as communidades (environmental education - community level)
27. involve local politicians in the conservation actions
28. develop collaboration between all of the social sectors (e.g. govt, ngos, universities)

29. need for coordinate a structure for muriqui conservation (Brazilian)
30. role of captive breeding?
31. Aumento do habitat no norte (increase of the pop in the northern parts - habitat)
32. develop forest corridors between protected areas/populations
33. exchange of information between wildlife managers and basic/field researchers
34. link field studies with captive studies
35. improve capture techniques
36. Manejo das populacôas ameacadas (management of small populations)
37. need to make Caratinga a reserve
38. conservacao nas areas particulares (define the conservation processes in private areas/lands)
39. management of genetic diversity/variability
40. avoid inbreeding depression
41. re-stimulate public awareness campaigns in Brazil and abroad
42. disease studies
43. taxonomic units: 2 species?

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Section 2
Distribuição e Status das Populações Remanescentes de *Brachyteles arachnoides*

Distribuição e Status das Populações Remanescentes de *Brachyteles arachnoides*

Participantes:
Anthony B. Rylands
Claúdio P. Nogueira
Luiz Claúdio Pinto
Russel A. Mittermeier
Sérgio L. Mendes
Vania Luciane A. G. Limeira

Objetivos:

O grupo usou como estratégia de trabalho a elaboração de uma tabela na qual foram reunidas todas as informações sobre a distribuição e status de *B. arachnoides,* a fim de estabelecer áreas prioritárias que deverão ser incluídas num grande programa de levantamento para a avaliação da situação atual das populações remanescentes. Além disso, esta tabela ajudará na elaboração de recomendações relacionadas com a sua conservação e manejo.

Critérios e Definições para os Dados da Tabela:

Número (No.)
Número da localidade e referência no mapa de distribuição.

Localidades (LOCALIDADE)
Nomes das localidades ou regiões nas quais *B. arachnoides* foi localizado, censurado, estudado ou, apenas, relatada sua ocorrência.

Coordenadas (COORD)
Coordenadas geográficas foram fornecidas baseadas nas informações disponíveis.

Áreas (AREA)
O tamanho de cada localidade também foi copilado a partir das informações disponíveis.

Fontes (FONTE)
Referência bibliográfica na qual foi extraída algumas informações contidas na tabela.

Continuidade do habitat (CONTI)
Determinação do grau de fragmentação na localidade que é definida como:
Fragmentada (F) = quando a localidade está localizada próxima de outros fragmentos;
Isolada (I) = quando a localidade está distante de outros fragmentos.

Estimativas da População de *B. arachnoides* (POPULAÇÃO)

Aguirre
Trabalho clássico e bastante abrangente no qual foram avaliadas pela primeira vez a distribuição e situação de muriqui pôr toda mata Atlântica. Em muitas localidades mencionadas pôr este pesquisador estimativas populacionais de muriqui são fornecidas, mas devido ao tempo e aos processos contínuos de desmatamento deste habitat achou-se melhor não considera-las para a determinação da densidade.

Presença
Ocorrência mais atualizada da presença (+) ou presença não confirmada mas provável (?).

Qualidade dos Dados
Relatado (R); Avistada (A); Estimado (E)

Densidade
Baixa (B)= < 1 ind/km2;
Média (M) = ≥ 1 ind/km2 e < 10 ind/km2;
Alta (A) = ≥ 10 ind/km2.

Número
Número de indivíduos baseado em informações mais recentes.

Survey
Alta prioridade = 1; Média prioridade = 2; Baixa prioridade = 3.

OBS: as áreas de alta prioridade foram baseadas nos seguintes critérios: Grau fragmentação; limites de distribuição das subespécies; falta de informação mais atualizada.

Status
Área privada = PR
Parque Estadual = PE; Parque Nacional = PN;
Reserva Biológica Estadual = RBE; Reserva Biológica Federal = RBF;
Reserva Municipal = RM;
Área de Proteção Ambiental Estadual = APAE; Área de Proteção Ambiental Federal = APAF;
Reserva Particular do Patrimônio Natural = RPPN;
Estação Ecológica Estadual = EEE; Estação Ecológica Federal = EEF

Tamanho da área
Categorias: Pequena = < 500 ha; Média = ≥ 500 ha e < 5000 ha; Grande = ≥ 5000 ha

Ameaça
1- Perda de habitat

2- Caça
3- Desconhecida
4-- Indireta

<u>Translocação</u>
`Área possíveis para translocação: Sim (S); Não (N)
Retirar e/ou

<u>Recomendações</u>

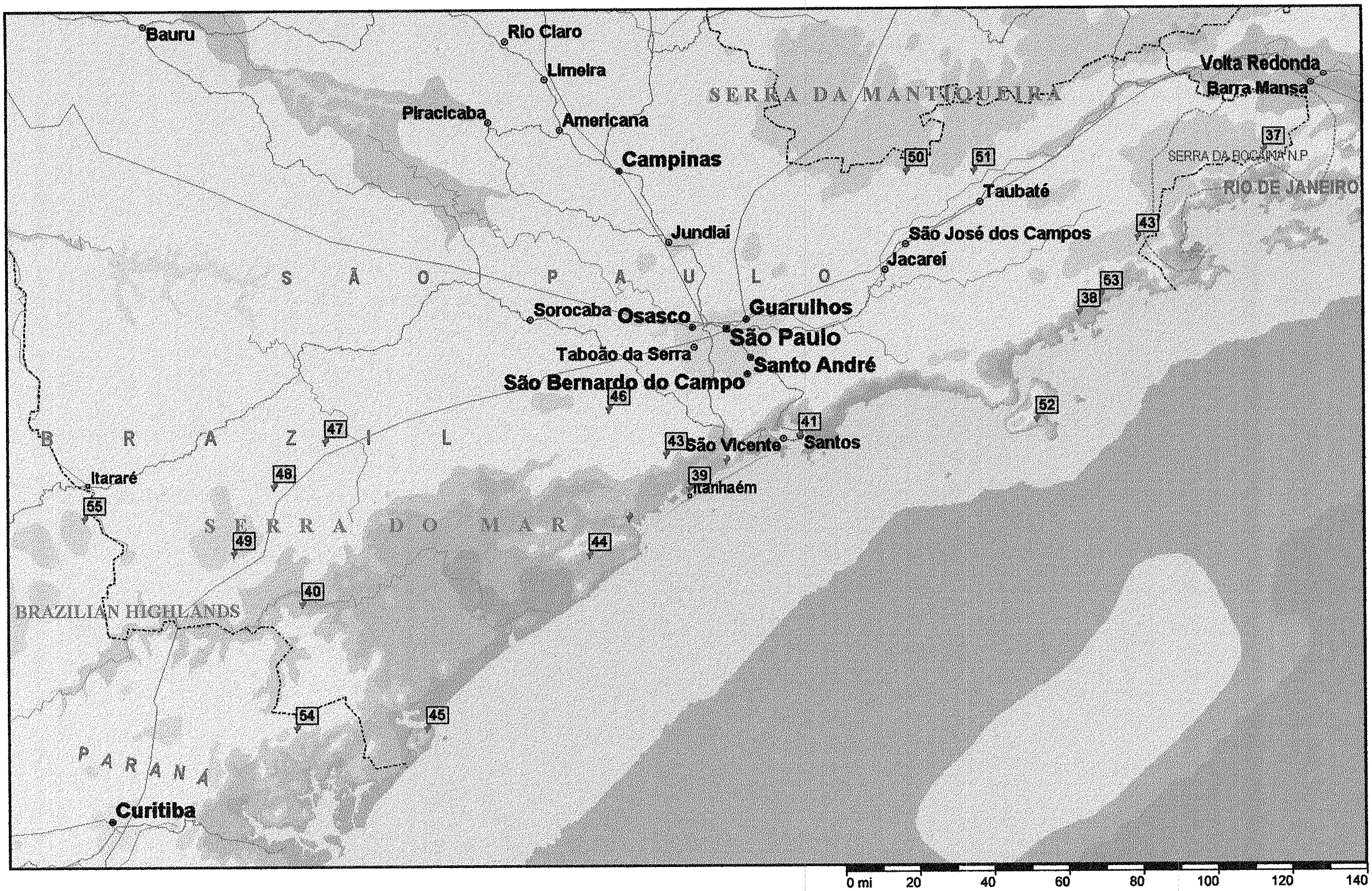
O grupo considera prioritária a implementação de um amplo programa de “survey” para mapear a situação atual de *Brachyteles*, identificando as áreas onde a espécie ainda ocorre e estimando, quando possível, o tamanho das populações.

Para o desenvolvimento do censo será necessário a organização de um grupo de pesquisadores (comitê), com representantes dos estados onde ocorre Brachyteles, que deverá estabelecer metodologias padronizadas para o “survey”, incluindo entrevistas, censos e diagnóstico de habitat.

As áreas consideradas prioritárias para o “survey” deverão ser aquelas mais fragmentadas e isoladas, que se concentram nos estados de BA, MG e ES.

No	UF	LOCALIDADE	COORD	ÁREA (ha)	ALT	FONTE	CONT	AGUIRRE	PRES	DADOS	DENS	NÚN	SUR VEY	PROT	ÁREA	AMEAÇA	TRA NS
1	BA	Pau Brasil – Córrego Mundo Novo		?		1	I	50-60	?	-			1	PR	P	1;2	N
2	BA	Caatiba/Itapetinga/Macarani		?		1	I	60-70	?	R			1	PR	P	1;2	N
3	BA	Guaratinga – Jucurucu		?		1	I	35-40	?	-			1	PR	P	1;2	N
4	BA	Chapori – Una		?		1	F	30-35	?	-			1	PR	P	1;2	N
5	BA	Encruzilhada – Serra do Pateirão / Ribeirão do Largo		?		1	I	35-40	?	-			1	PR	P	1;2	N
6	BA	Serra da Gabiarra – Santa Cruz de Cabrália		?		1;2	F	70-80	?	R			1	PR	P	1;2	N
7	BA	Fazenda Pontal – Itamaraju		?		3	?		?	R			1	PR	P	1;2	N
8-a	BA	Vizinhança de Jussari		?		4	F		?	R			1	PR	P	1;2	N
8-b	BA	Fazenda Teimoso – Jussari		240		5	F	5	?	R			1	RPPN	P	1;2	N
9	BA	Serras Buerarema/Arataca		?		4	F		?	R			1	PR	M	1;2	N
10	BA	Maraú/Camamú		?		4	F		?	R			1	PR	M	1;2	N
11	BA	Nova Canaã		?		4	I		?	R			1	PR	P	1;2	N
12	BA	Vizinhança de Belmonte		?		2	F		?	R			1	PR	M	1;2	N
13	BA	Fazenda Tuití		?		6	I		?	R			1	PR	P	1;2	N
14	MG	P.E. Serra do Brigadeiro	20 43'S-42 1'W	13210		1;7	F	50-60	+	E		40	2	PE	M	1	N
15	MG	Córrego de Areia		60		8	I		?	A		8	1	PR	P	1;2	N
16	MG	Pque Estadual do Rio Doce		36000		1;9	I	200-250	+	A		21	3	PE	G	1	S
17	MG	Estação Biológica de Caratinga		860		1	I	20-25	+	E		90	3	PR	M	2	N
18	MG	Fazenda Esmeralda – Rio Casca		44		1	I	8	+	E		12	1	PR	P	2	N
19	MG	RPPN Mata do Sossego e vizinhança – Manhuaçú		800		1	I		+	A		21	2	RPPN /PR	M	2	N
20	MG	Pque Estadual da Serra de Ibitipoca	21 33'S-43 36'W	1488		10	F		+	A		2	1	PE	M	1;2	N
21	ES	Rebio Augusto Ruschi – Santa Teresa		4000		1;11	F	150-180	+	E			1	REBI O	M	3	S
22	ES	Jatibocas – Itarana		?		1	F	8	+	R			1	PR	P	3	N
23	ES	Barra Encoberta – Itarana		?		1	F	12	?	-			1	PR	P	3	N
24	ES	Rio Bonito/Caramuru – Santa Leopoldina		?		12	F		?	-			1	PR	P	1;2	N
25-a	ES	Alfredo Chaves/Pedra Azul/Domingos Martins		?		1	F	15-20	?	-			1	PR		3	N
25-b	ES	P.E. Pedra Azul		1240		1	F		?	-			1	PR	G	3	N
26	ES	Pque Nacional de Caparaó		26000		8	F		+	A		19	2	PE		3	P
27	ES	Brejetuba – Afonso Cláudio		?		1	F	40-50	?	-			1	PR		1;2	N
28	ES	Serra das Torres – Mimoso do Sul		?		12	F		?	-			1	PR		1;2	N
29	RJ	Santa Maria Madalena (Pque Desengano)		22400		1	I	150-170	+	A			1	PE	G	3	?
30	RJ	Silva Jardim / Cachoeiras de Macacu / Friburgo		9000		1	F	160-190	?	-			1	PR	G	3	N
31	RJ	Pque Nacional da Serra dos Órgãos		10500		1	F	80-100	?	-			3	PN	G	3	?

		(Magé / Teresópolis)															
32	RJ	Reserva Biológica do Tinguá		20000		8	F		?	-			1	RBE	G	3	?
33	RJ	Pque Nacional de Itatiaia (Rezende)		12000		1	F	60-80	?	-			3	PN	G	3	?
34	RJ	Horto Florestal de Mambucaba – Angra dos Reis*		12220		1	F	200-230	?	-			1	HF	G	3	?
35	RJ	Pque Nacional da Bocaina	22 50'S-44 15'W	120000		1	F		?	-			3	PN	G	3	P
36	RJ	APA de Cairuçú - Parati	23 15'S-44 37'W	33800		13	C		?	-			3	APA	G	3	?
37	SP	São José do Barreiro – Bananal – Bocaina		40000		1	F	200-250	+	R			3	PR		3	?
38	SP	Ubatuba – São Luiz do Piraitinga – Alto Paraíba		160000		1	C	180-200	+	R			3	APA	G	1;2	N
39	SP	Serra do Paranapiacaba		680000		1	C	400-450	+	R			3	PE/PR	G	1;2	N
40	SP	P.E. Jacupiranga / Barra do Turvo	24 38'S-48 23'W	150000		1	C	180-200	+	A		3	2	PE	G	1;2	?
41	SP	Santos / Mogi das Cruzes / Salesópolis		35000		1	C	280-300	?	-			3	APAE	G	3	N
42	SP	Barreiro Rico – Anhembi		3259		1	I	50-60	+	E		95	1	PR	M	3	N
43	SP	Pque Estadual da Serra do Mar		309938		1	C		+	R		25	1	PE	G	1;2	P
		Núcleo Curucutu	23 47'S-46 25'W	23697		13	C		+	A		2	3	PE	G	3	P
		Mongaguá	23 55'S-4 00'W	30000		13	C		+	A		2	3	PE	G	3	P
		Pedro de Toledo/Itariri	24 10'S-47 07'W	10250		13	C		+	A		4	2	PE	G	2	P
		Cunha		2230		8	C		+	A		16	3	PE	G	3	P
44	SP	Estação Ecológica Juréia / Itatins	24 30'S-47 15'W	82000		13	C		+	A		8	3	EE	G	3	P
45	SP	Pque Estadual da Ilha do Cardoso	25 03'S-47 53'W	22500		13	I		+	A		6	3	PE	G	2	P
46	SP	Pque Estadual do Jurupará		26250		13	C		+	A		5	3	PE	G	3	P
47	SP	Pque Estadual de Carlos Botelho		37797		8	C		+	E		500	3	PE	G	2	P
48	SP	Parque Estadual Intervales	24 11'S-48 23'W	49888		14	C		+	E		400	3	PE	G	3	P
49	SP	Pque Estadual Turístico do Alto Ribeira	24 25'S-48 35'W	36910		1	C		+	A		12	3	PE	G	3	P
50	SP	São Francisco Xavier – São José dos Campos		10000		13;15	F		+	E		30	3	PR	G	1	N
51	SP	Faz. S. Sebastião do Rib. Grande - Pindamonhangaba		1206		16	F		+	E		22	3	PR	M	1	N
52	SP	Parque Estadual de Ilhabela		27025		17	I		+	A		1	2	PE	G	1	P
53	SP	Fazenda Escorregosa - Ubatuba		?		18	?		+	R			1	PR		2	N
54	PR	APA de Guaraqueçaba / Maciço do Paraná	25 05'S-48 10'W	80000		13	C		+	A		2	1	APA	G	3	?
55	PR	Jaguariaiva	24 15'S-49 30'W	?		13	C		?	R			1	PR		2	?



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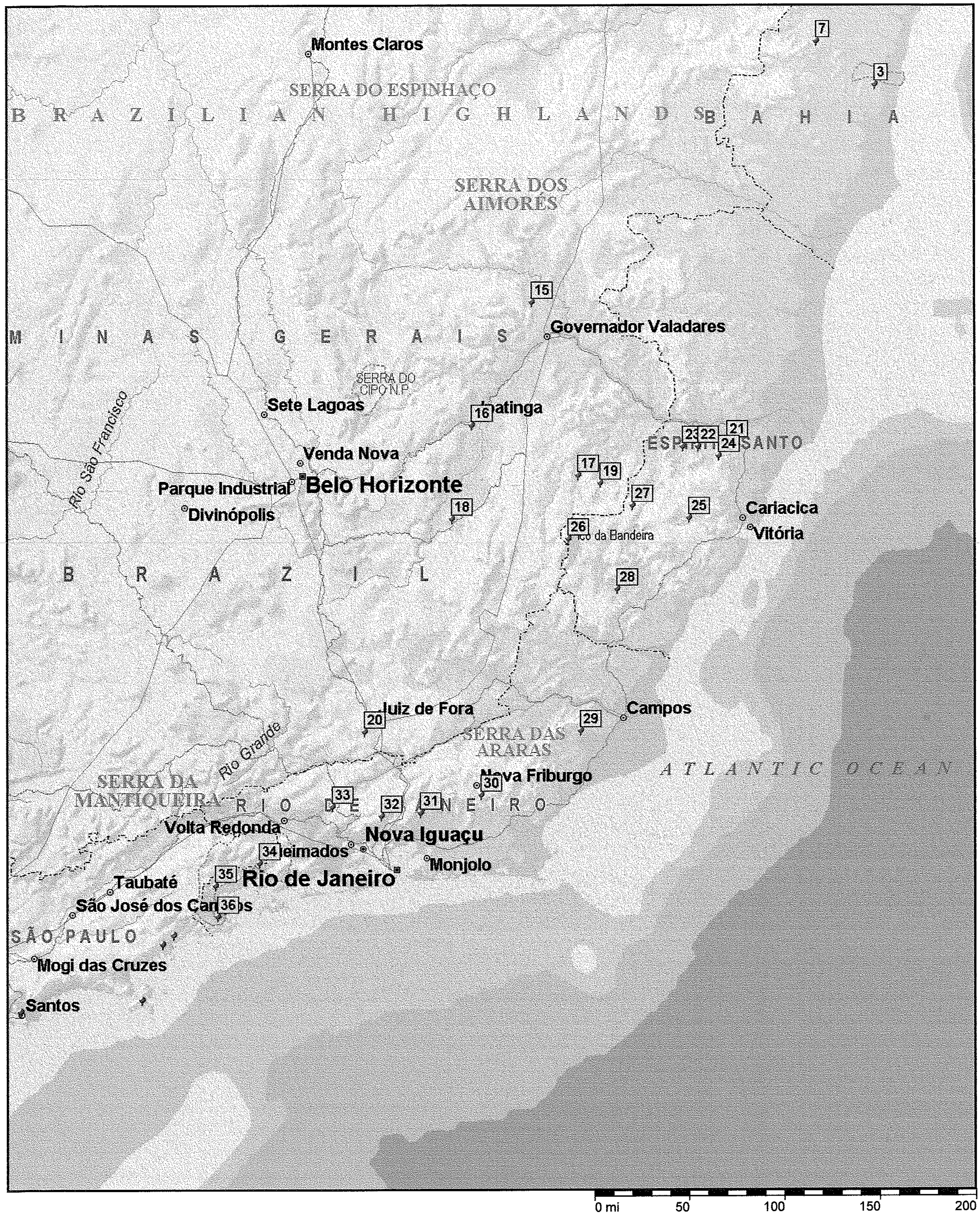
Muriqui Distribution
Southern Population



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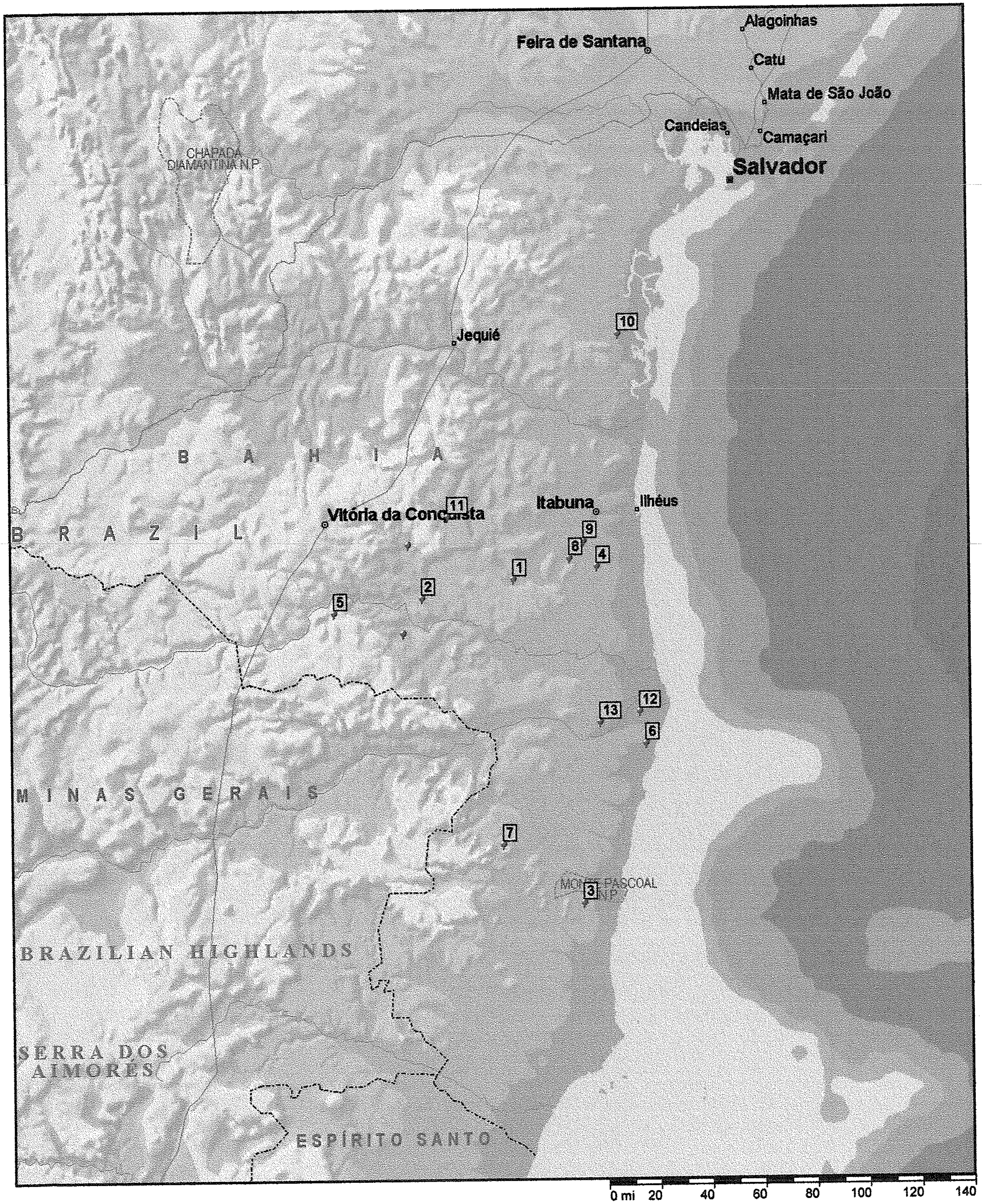
Muriqui Distribution
Northern Population



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Muriqui Distribution
Northern Population

POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA) FOR THE MURIQUI (*Brachyteles arachnoides*)

Belo Horizonte, Brazil
23 - 26 May 1998

Report

Section 3
Habitat and Population Management Working Group Report

Habitat and Population Management Working Group

Participantes:

Liege Mariel Petroni
Claudia Guimaraes Costa
Laiena Ribeiro Teixeira Dib
Andre Hirsch
Marilene Mesquita Silva
Rosa Lemos de Sa

Problemas identificados em plenaria:

1- Priorizar Acoes
2- Maximizar Conhecimentos Existentes
3- Recursos Financeiros
4- Papel da Criacao em cativeiro
5- Aumento do Habitat
6- Criacao de Corredores entre areas
7- Ligacao entre estudos de campo e cativeiro
8- Melhores tecnicas de captura
9- Manejo das Populacoes ameacadas
10- Necessidade de transformar Caratinga em reserva
11- Definir processos de conservacao em areas particulares
12- Troca de informacoes entre pesquisadores e manejadores de vida silvestre

1. Prioritize Actions
2. Maximize the use of existing knowledge
3. Funding
4. Role of captive breeding
5. Carrying capacity
6. Develop forest corridors between protected areas and populations
7. Link field and captive studies
8. Improve captive techniques
9. Management of small populations
10. Need to make Caratinga a Reserve
11. Define the conservation processes in private areas and lands
12. Exchange of information between wildlife managers and basic field researchers.

Introduction

The Brazilian Atlantic forest constitutes a unique biome characterized by high species diversity and high levels of endemism. A long history of land clearing for crops, pastures, timber and firewood has resulted in over two centuries of widespread destruction. The remaining forest patches are small, isolated and unprotected. In order to preserve some of the original diversity of the Atlantic forest, urgent efforts must be channeled toward protecting the remaining forest fragments (Fonseca, 1985).

The muriqui, or woolly spider monkey, *Brachyteles arachnoides*, as the largest Neotropical Primate, has become a flagship species, a vivid symbol representing the entire Atlantic forest of southeastern Brazil (Strier, 1992). Since the muriqui is endemic to this vanishing forest, there is a general agreement about the urgent need for a management plan for the conservation of the species (*e.g.*Fonseca, 1985; Strier, 1992, 1993; Mendes e Chiarello, 1994; Mendes, 1994).

During the “Population and Habitat Viability Assessment (PHVA) for the Muriqui”, a group was formed to discuss and propose management strategies for the conservation of the species. In order to make the theoretical discussion easier, the proposed strategies were treated as “Habitat Management” or “Population Management”, despite of the fact that they can be used as integrated management tools.

Twenty-four different possible scenarios were identified based on: size and conservation status of the area; population density and kind of threats, as follows:

FOREST SIZE:
small: < 500 ha.
medium: 500 - 5000 ha.
large: > 5000 ha.
Rationale: according to De Paula *et al* (1997), there are few forest fragments bigger than 500ha. in the original distribution area of muriqui in Minas Gerais. Thus, we assumed this value as the limit to distinguish between small and medium size areas.

FOREST CONSERVATION STATUS:
private
governmental
Rationale: we consider that governmental and private areas should be treated differently because we assume that in the former official patrol and control is or should be present.

POPULATION DENSITY:
high: < 0,15 individuals per ha.
low: > 0,15 individuals per ha.
Rationale: considering the carrying capacity as 0,3 individuals per ha. (see Strier, 1993-1994), we decided to use the value of 0,15 individuals per ha. (50%) as the average density.

KINDS OF THREATS:
direct: loss of habitat and hunting
indirect: forest product extractive activities, water pollution etc.
Rationale: we consider as direct threats those that will eliminate the animals, and as indirect threats those that will affect the population in some way.

All 24 scenarios are presented in Figure 1. Of the 24 possible scenarios only 11 were identified so far in the literature in all six states (Bahia, Espirito Santo, Minas Gerais, Rio de Janeiro, Sao Paulo and Parana) (Table 1 and Figure 2).

Figure 1. Diagramatic representation of the 24 possible cases identified.

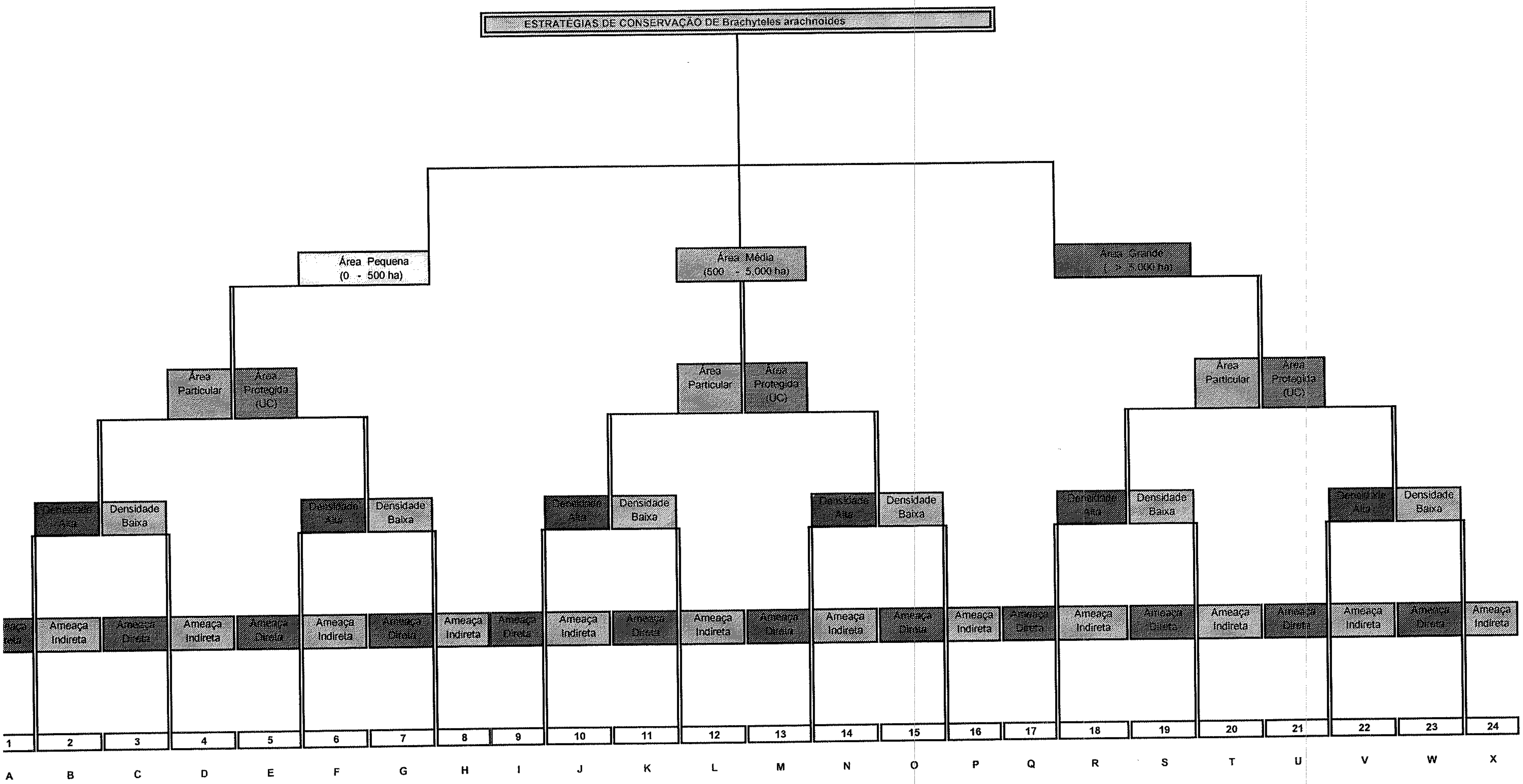
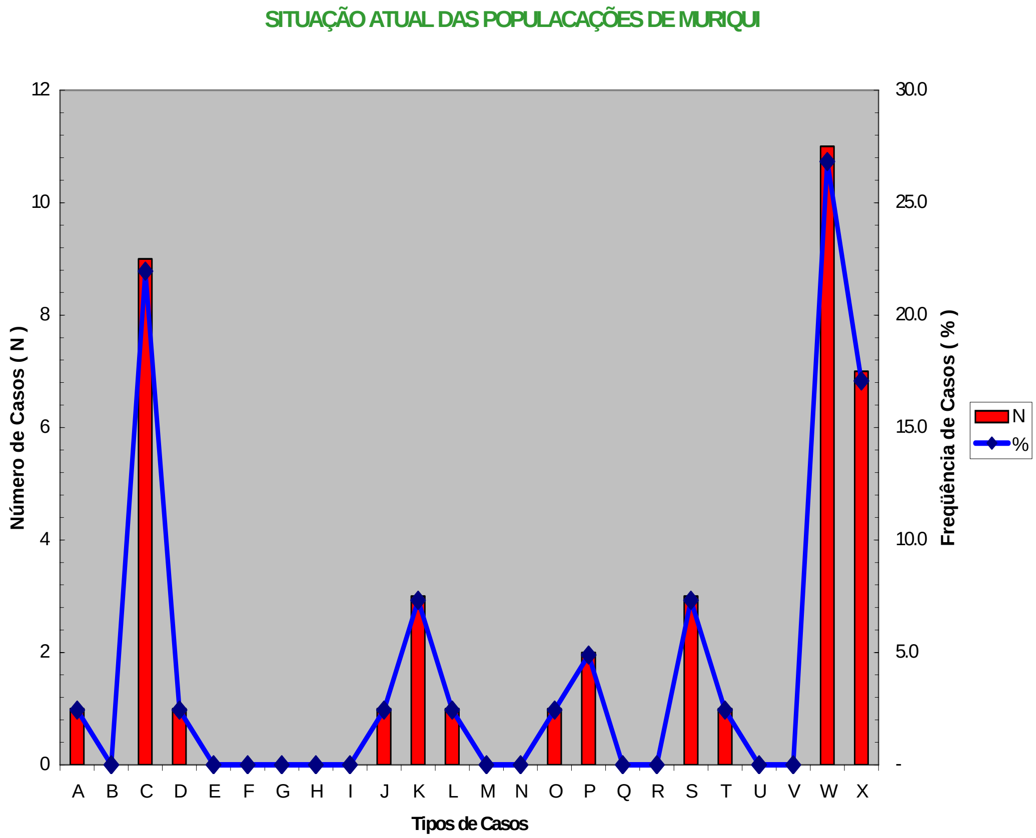


Table 1. Frequency of the 24 possible identified cases.

Tipo de Caso	Tamanho da Área (ha)	Categoria da Área	Densidade Populacional (indiv./ha)	Tipo De Ameaça	Freqüência de Casos		Localidades
					(N)	(%)	
A	Pequena	Particular	Alta	Direta	1	2.5	Faz. Esmeralda
B	Pequena	Particular	Alta	Indireta		-	
C	Pequena	Particular	Baixa	Direta	9	22.5	Cór. Da Areia, Faz. Ramaiana, Faz. Aulo Bebert, Blemonte, Faz. Tuití
D	Pequena	Particular	Baixa	Indireta		-	
E	Pequena	Protegida	Alta	Direta		-	
F	Pequena	Protegida	Alta	Indireta		-	
G	Pequena	Protegida	Baixa	Direta		-	
H	Pequena	Protegida	Baixa	Indireta		-	
I	Média	Particular	Alta	Direta		-	
J	Média	Particular	Alta	Indireta	1	2.5	EBC
K	Média	Particular	Baixa	Direta	3	7.5	Barreiro Rico, S. Sebastião do Rib. Grande (Pindamongamgaba) e Faz. N. Sra. Das Graças
L	Média	Particular	Baixa	Indireta	1	2.5	RPPN Mata do Sossego
M	Média	Protegida	Alta	Direta		-	
N	Média	Protegida	Alta	Indireta		-	
O	Média	Protegida	Baixa	Direta	1	2.5	Cuniha
P	Média	Protegida	Baixa	Indireta	2	5.0	PE do Ibitipoca e Sta. Tereza
Q	Grande	Particular	Alta	Direta		-	
R	Grande	Particular	Alta	Indireta		-	
S	Grande	Particular	Baixa	Direta	3	7.5	Silva Jardim, Cachoeiras de Macacu e Friburgo
T	Grande	Particular	Baixa	Indireta	1	2.5	S. Francisco Xavier
U	Grande	Protegida	Alta	Direta		-	
V	Grande	Protegida	Alta	Indireta		-	
W	Grande	Protegida	Baixa	Direta	11	27.5	PE Rio Doce, PE Serra do Brigadeiro, PE do Desengano, PE Serra do Mar, Juréia, Jacupiranga, Carlos Botelho, PETAR, Ju-Paraná, I. Dp Carloso, Bocaina
X	Grande	Protegida	Baixa	Indireta	7	17.5	PARNA Caparaó, PARNA Itatiaia, Faz. Intervales, Oairuçu, APA Guaraqueçava

Figure 2. Absolute and relative frequency of the 24 possible cases identified.



Possible Management Scenarios and Recommendations

Case A - small and private area, high density, direct threat = 1 area
Example: Faz. Esmeralda
Recommendations: 1) Start environmental education program and ecotourism
2) Translocation
3) Start a reforestation/natural regeneration program
4) Create corridors to connect forest patches

Case C - small and private, low density, direct threat = 9 areas (22%)
Example: Faz. Córrego da Areia
Recommendations: 1) Carry out environmental education program within areas as well as in the buffer zone
2) Start a reforestation/natural regeneration program
3) Create corridors when appropriate/possible

Case J - median and private area, high density, indirect threat = 1 area
Example: Estação Biológica de Caratinga - EBC
Recommendations: 1) Continue environmental education program and ecotourism
2) Continue reforestation/natural regeneration program
3) Transform to a protected area: RPPN (?)
4) Continue research

Case K - median and private area, low density, direct threat = 3 areas
Example: Barreiro Rico
Recommendations: 1) Transform to a protected area:
2) Start environmental education program and ecotourism
3) Start a reforestation/natural regeneration program
4) Start basic population research

Case L - median and private area, low density, indirect threat = 1 area
Example: RPPN Mata do Sossego
Recommendations: 1) Continue environmental education program
2) Continue a reforestation/natural regeneration program
3) Start basic population research

Case O - median and protected area (UC), low density, direct threat = 1 area
Example: Cunha
Recommendations:
1) Promote law enforcement
2) Start environmental education program and ecotourism
3) Start basic population research

Case P - median and protected area (UC), low density, indirect threat = 2 areas
Example: PE do Ibitipoca
Recommendations:

1) Promote ecotourism
2) Start basic population research
3) Promote law enforcement

Case S - large and private area, low density, direct threat = 3 areas
Example: Serra de Macacu
Recommendations:

1) Transform to a protected area:
2) Start environmental education program and ecotourism
3) Start basic population research
4) Environmental Impact Study (EIA)
5) Translocation, in the future

Case T - large and private area, low density, indirect threat = 1 area
Example: São Francisco Xavier
Recommendations:

1) Transform to a protected area:
2) Start environmental education program and ecotourism
3) Start basic population research
4) Environmental Impact Study (EIA)
5) Translocation, in the future

Case W - large and protected area (UC), low density, direct threat = 11 areas (26.8%)
Example: PE do Rio Doce
Recommendations:

1) Promote law enforcement
2) Start environmental education in the buffer zone
3) Start basic population research

Case X - large and protected area (UC), low density, indirect threat = 7 areas (17.1%)
Example: PE Intervales
Recommendations:

1) Start environmental education in the buffer zone
2) Start basic population research
3) Start ecotourism program

Case Specific Recommendations

1. Environmental Educational in the Buffer Zone Program
   Cases: A, C, J, K, L, O, P, T, W and X

2. Translocation Program

Cases: A; S in the future

3. Reforestation / Natural Regeneration and Corridors Program
   Cases: A, C, J, K and L

4. Analysis of Potential Ecotourism Program
   Cases: in all the cases

5. Basic Population Research Program
   Cases: in all the cases

6. Transform to Protected Area
   Cases: A, C, J, K, L, S and T

7. Law Enforcement Program
   Cases: in all protected areas - O, P, W and X

General recommendations:

Translocation: preferably young females at reproductive age should be captured and translocated from small areas with high density to large well protected areas with low population densities. (The sources for the animals to be translocated needs further analysis and discussion since disagreement on this point has emerged – editors). Translocation of entire groups is not recommended.

Environmental education: selection of priority areas for Environmental Education programs should be based on:

a) available logistics / accessibility to area
b) presence of local NGOs,
c) pre-disposition of land owner (in case of private areas),
d) degree of threat (high x low human pressure)

Ecotourism: before starting any ecotourism initiative a viability study should be carried out for the proposed site

Increase habitat:
a) private lands = natural regeneration and reforestation should be considerate to increase core areas, and the creation of corridor when there is a possibility to connect isolated patches of forest.
b) protected areas = recuperation of habitat should be carried out when appropriate

Creation of Private Reserves: an attempt should be made to create private reserves (RPPNs) where private areas are identified as extremely important for the conservation of the species. (Criteria for establishing importance to be defined)

POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA)
FOR THE MURIQUI
(*Brachyteles arachnoides*)

Belo Horizonte, Brazil
23 - 26 May 1998

Report

Section 4
IMPACTOS SOCIAIS, ECONOMICOS E POLITICOS NAS POPULACOES DE *BRACHYTELES ARACHNOIDES*

IMPACTOS SOCIAIS, ECONOMICOS E POLITICOS NAS POPULACOES DE BRACHYTELES ARACHNOIDES

Participants:
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Lêda Luz
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Gayl Ness
Harrie Vredenburg
Eduardo Marcelino Veado

Human Impacts on Muriqui
Our first task was to list all of the important human impacts on the muriqui. Twelve were identified:

1. **Coffee planting**	**Increasing**	**Major impact**
2. **Cattle grazing**	**Increasing**	**Major Impact**
3. **Fire for pasture clearing**	**Increasing**	**Major Impact**
4. **Pollution fert. + insecticides**	**Increasing**	**Unknown**
5. **Harvesting palm hearts**	**Increasing**	**Major Impact**
6. **Small scale timber harvesting**	**Increasing**	**Major Impact**
7. **Firewood harvesting**	**Stable**	**Minor impact**
8. **Roads & traffic**	**Increasing**	**Major Impact**
9. **Park infrastructure**	**Stable**	**Minor Impact**
10. **Hydroelectric**	**Increasing**	**Major Impact**
11. **Untreated sewage**	**Increasing**	**Uncertain, future impact**
12. **Hunting for food (associated with 5)**	**Stable**	**Uncertain**

These impacts were known to be different in different major regions of the Muriqui. The two major regions were those in the North and South. The North is identified as the state of Minas Gerais, the South by the state of Sao Paulo. For each region the impacts can be prioritized, and ranked from highest to lowest.

PRIORITIES

Minas Gerais (Fragments of forests)	Sao Paulo (120,000 ha state)
1. Coffee Planting	1. Harvest Palm Hearts
2. Cattle grazing	2. Roads & Traffic

3. Fire for land clearing
4. Small scale timber harvesting
5. Firewood harvesting

3. Hydroelectric
4. Hunting for food

In plenary session the larger group made the following comments:

- Mining: In specific areas of Muriqui habitat, this does have an impact. There are legal disputes now in some protected areas over access to mineral rights.
- We need more precise information on the increase of coffee planting, and its specific impact on Muriqui habitat.
- We need more precise information on the increase, or change, of cattle production and pasture lands, and the impact of this change on Muriqui habitats.

It will be useful to provide details on the **processes** by which these human activities affect the Muriqui habitat, so that one can propose alternatives to those activities that have an especially negative impact.

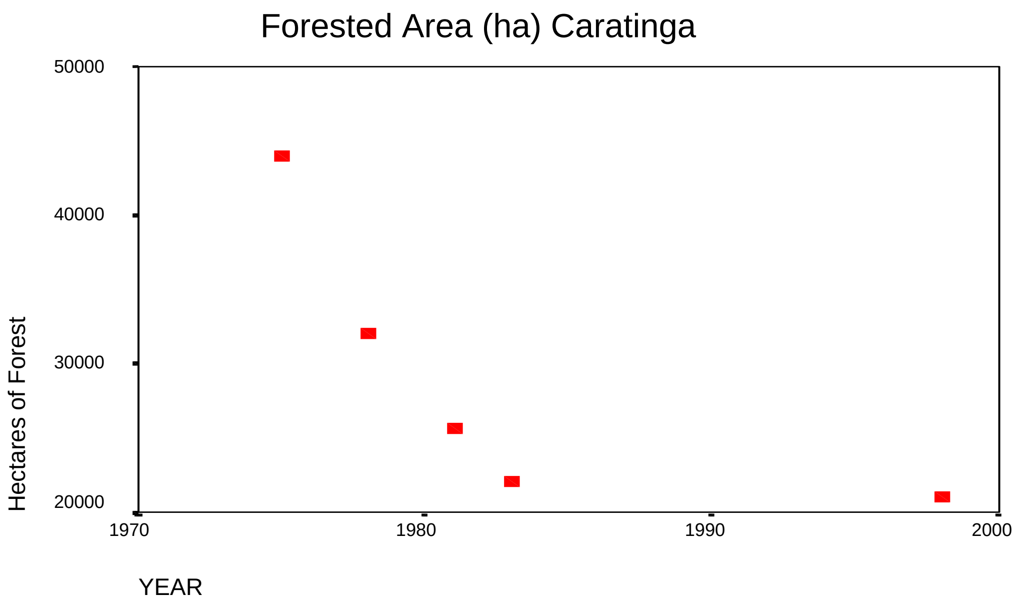
Following these suggestions, the group returned to two specific areas to describe the impacts and attempt to make estimates of their magnitude. The two specific locations were Caratinga and Carlos Botello State Park.

Habitat loss in Caratinga

Caratinga is an especially important location, since it has a population of 120 muriqui, which is the largest population in the state of Minas Gerais. Expanding coffee planting is occurring but it is areas of pasture and already deforested areas so it is not a cause of current habitat loss for the Muriqui. Although there has also been substantial land clearing in the past for pasturage and cattle raising, the area of forest is now increasing.

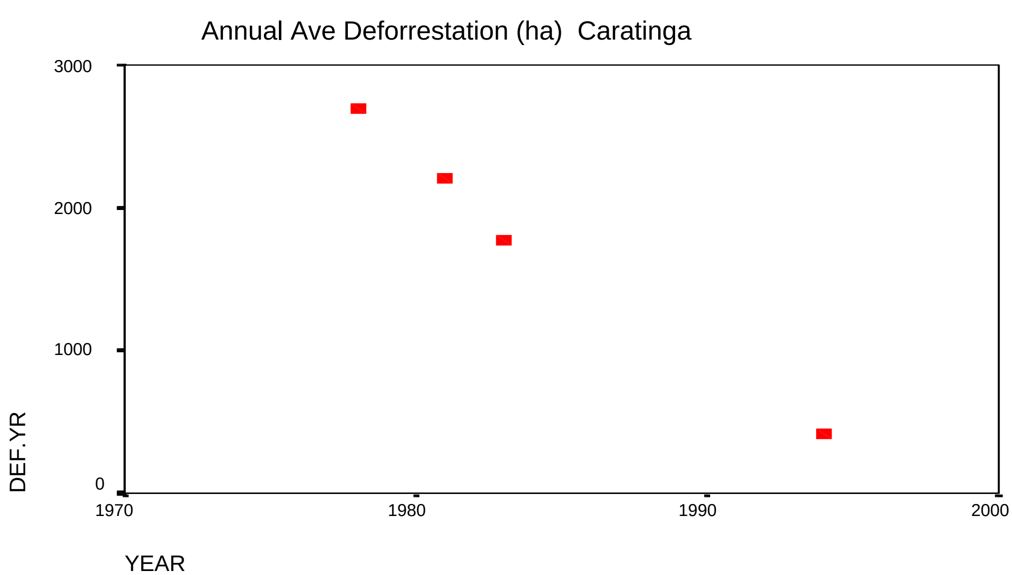
Using previously published data and 1994 data from the Caratinga biological station, produces the following estimates of historical forest loss.

A. Estimates of forest loss in Caratinga.

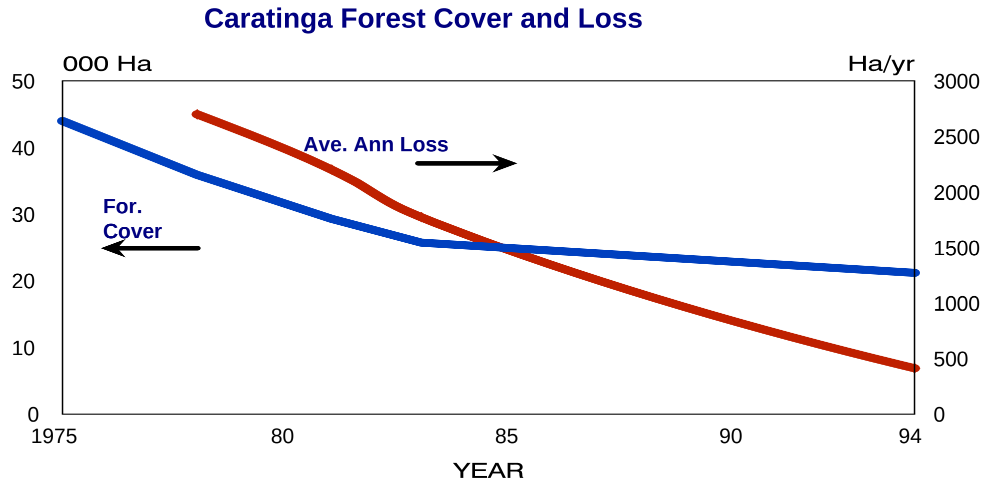


These data are from Fonseca (1985) for the first four data points. The fourth point (est 21,211 ha of forest) is from data provided by Eduardo Veado from the Biological Station of Caratinga,

B. From above, derived estimates of the average annual deforestation since 1975 are as follows.



C. Putting the two sets of data points together provides the following graph:



Since 1983 the forest loss has averaged 413 ha per year, or 1.9% of the 1983 forest size. Losses at present are due only to selective logging. The actual area of forest cover is now increasing.

The comparable figure of loss for Minas Gerais as a whole is 1.46% per year for the period 1990-95.

We therefore suggest a range of annual historical habitat loss from 0% to 1.4% to 1.9% for the Caratinga Muriqui population. We are uncertain of the time horizon for potential continuing loss, implying that VORTEX runs need to be done for 10, 20, 30 etc years.

<u>Palm Heart Harvesting and Hunting in Carlos Botello State Park</u>

Carlos Botello State Park, 37,000 ha., with an estimated Muriqui population of 500 to 800, faces a different problem. It is a protected area, but there is illegal harvesting of palmito, palm hearts, from the park. While this does not destroy the Muriqui habitat, it reduces habitat quality. When palm trees are cut down for the heart, the monkeys retreat from the disturbed area. They return when the harvesting is completed, but this implies a reduction of the carrying capacity, or the upper density levels that can be sustained. There is also harvesting of monkeys for meat by the palm cutters.

Cutting palm trees is now illegal in Sao Paulo state. For some years it was legal, leading people to plant plantations. After three years, the law was changed to prohibit cutting. This destroyed commercial plantations and led to illegal harvesting in the state park. There is a large market demand for palm hearts, and harvesters can make as much as Rs 100 a day, or Rs 2000 a month, which is a substantial sum. The attraction is greater due to the relatively high unemployment, especially for young men. One case Mauricio Talebi Gomes experienced in the Park is illustrative. An urban entrepreneur collected a team of 5-8 men, and drove them to the forest border. The workers spread out, felled palm trees (e.g. 10 meters in height), then cut the top one meter where the heart is. The heart logs may be bundled up and picked up by the boss at night and transported to town for processing. This involves cutting and cooking the hearts then packing them in jars. It is sometimes preferred, however, to do the processing in the forest, using local wood to cook the hearts and bottle them there. Crews are concerned about Park wardens and have an extensive series of signals to warn one another when the wardens may come around. The work teams have to be self sufficient, so they hunt the monkeys for meat.

It is difficult to estimate the number of monkeys killed, but the working group made an estimate (guess) that it might be 5-10 per year. This might be a very conservative guess, however, since one team apprehended by the police was found to have 12 dead monkeys, another had three adults and two sub-adult bodies. The hunters do not distinguish between males and females, so we can assume the same proportion of females are taken in an average population.

This type of palm heart harvesting has been going on for the past 10-15 years. One crude guess is that some 5000 trees will be cut for the hearts per month. One good harvester can cut perhaps 50 trees per day. Estimated 3 teams, or 15-24 people, will be in the forest at any one day. The trees are most dense at 30 to 200 meters in altitude. This area has been extensively cut over. Ideally a tree will be cut at seven years, giving a one meter heart at the top just under the foliage. With extensive cutting, it is now common to take trees that are only 3-4 years old, with smaller hearts, of perhaps one half meter.

Cutting goes on all year, but there is some seasonality. Cutting takes place especially on weekends or during major sporting events (soccer, world cup etc) when the cutters know the guards will be off duty or watching TV and not the forests.

Recomendacoes e Sugestoes

Muriqui como especie-bandeira, valorizar e divulgar esta idei autilizar este argumento em relacao a todas as iniciativas empreendi das com as comunidades de entorno.

1) Regulamentar a extracao do palmito e providenciar fontes de proteina animal para as populacoes locais das comunidades de entorno. Providenciar desta forma fontes alternativas de alimento, buscando minimizar a caca de muriquis selvagens.

2) Estabelecer oficialmente uma organizacao nao governamental local com intuito de coordenar as atividades relacionadas a conservacao do muriqui na regiao do Parque Estadual de Carlos Botelho, em primeira instancia.

3) Oficializar uma rede de relacoes de pessoas locais interessadas na preservacao do meio ambiente, promovendo desta froma um maior envolvimento dos diferentes setores da comunidade.

<u>Estrategias Locais Para a Conservacao</u>
Atuar nas comunidades locais da regiao sul do Estado de Sao Paulo, local onde estao localizados os remanescentes continuos da Mata Atlantica atraves de uma acao integrada nos diversos setores

<u>COMUNIDADES LOCAIS</u>

- Incentivo para exploracao comercial de cultura regional/ local (artesanato, e outras formas),obter fontes de renda alternativas, atraves da relacao conservacao e uso dos recursos naturais;
- Definicao de conceitos que auxiliem a questao de exploracao do palmito:
- Buscar estrategias e conceitos que auxiliem em relacao as atividades de caca de populacoes selvagens de muriquis.
- Proprietarios de areas de floresta privada
- Empresarios locais conservacionistas

<u>EDUCACAO AMBIENTAL</u>

- Estara atuando uma profissional especializada em Educacao Ambiental na Ongqye ja possui experiencia na mesma unidade de conservacao, atraves de trabalho desenvolvido durante varios anos.
- Palestras na Rede Publica de Ensino Local e na Capital de Sao Paulo:02 escolas municipais e 02 escolas estaduais em Sao Miguel Arcanjo e rede publicas municipal e estadual da capital de Sao Paulo
- Oficinas praticas em atividades relacionadas ao meio ambiente, em diferentes faixas etarias: promover a realizacao destas atividades para diferentes publicos-alvo oriundas de diferentes associacoes civis locais
- Lideres locais; eleicao de jovens lideres conservacionistas locais para atuacao nas proprias comunidades, em ambitos locais e regionais;
- Turismo: Definicao de criterios para a exploracao em conjunto com o municipio de Sao Miguel Arcanjo (estancia turistica estadual).

<u>PESQUISA COM FAUNA E FLORA</u>

- Definicao das prioridades: vegetacao e fauna

- Estabelecimento de linhas de pesquisa de longo prazo, visando conhecimento abrangente das caracteristicas da fauna e flora

- Compilacao das informacoes existentes para o muriqui, outros primatas, bem como outros estudos realizados com as diferentes especies animais;

- Definicao de linhas de pesquisa prioritarias, tracando estrategias de longo prazo de investigacao para especies chave, promovendo subsidios cientificos para a conservacao dos remanescentes continuos de floresta;

- Estabelecer prioridades para o inicio de pesquisas em diversidae biologica das unidades de conservacao
  - Localização e Implementação de novas àreas de ocorrência de muriquis, como potencias futuros sítios de estudos e pesquisa em vida livre.
  - Àreas de Unidades de Conservação no Estado de São Paulo, Estado do Paraná, e áreas privadas na região do PECB, bem como áreas privadas no norte do Estado do Paraná;

- Utilizar od dados cientificos disponiveis para contribuir na formacao do Plano de Gestao do Parque Estadual de Carlos Botelho.

A. Programa de conscientizacao ambiental: junto aos propritarios vizinhos veiculado pela radio; junto aos visitantes;

B. A possibilidade de ecoturismo; visitar florestas, rafting Rio Manhuacu;

C. A possibilidade de alternativas agro-ecologicas:
   1) Arvores de frutas
   2) Alternativas de producao e conservacao do café: para aumentar a produtividade do café, as praticas de rotina sao aumentar o uso de agrotoxicos,o que compromete o qualidade do solo da regiao. Desenvolver estrategias alternativas visando aumento da produtividade sem aumento da area de plantio.
   3) Plantio de eucaliptos para fazer lenha; pesquisar essencias nativas locais de crescimento rapido e potencial para combustao;
   4) Manejo de pasto busacndo aumentar a produtividade;
   5) Convencer os produtores de que a manutencao da floresta promove a protecao do pasto e controle de perda de solo por erosao;
   6) Diversificar o uso da terra: plantas ornamentais, medicinais, mel, bambu, pesque-pague (psicultura), producao de humus…

D. Pesquisa cientifica do potencial da floresta pra producao de madeira e frutas nativas, entre outros produtos, como criacao de animais silvestres para abate.
E. Promover um lobby com governos estadual e municipal (em relacao ao incentivo fiscal: desconto no ITR para quem ainda tem muriqui).
F. Utilizar resultados do workshop muriqui como argumento para a necessidade de conservacao do muriqui, {especially for populations that are at high extinction risks.} Usar este argumento com os proprietarios de terra, organizando um encontro para divulgar estas ideias; mobilizar a comunidade. Planos de longo termo, colocando para a populacao que seraomrealizados encontros periodicos.
G. Utilizar as ideias para a educacao ambiental, usando muriqui como um simbolo de qualidade.
H. Atividades de Educacao Ambiental, promovendo atividades na escola de Santo Antonio de Manhuacu.

POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA)
FOR THE MURIQUI
(*Brachyteles arachnoides*)

Belo Horizonte, Brazil
23 - 26 May 1998

Report

Section 5
Species Biology and Modeling Working Group Report

SPECIES BIOLOGY AND MODELING WORKING GROUP

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Introduction
Computer models that evaluate the probability of extinction, loss of genetic diversity, fluctuations in population size, impact of density dependence, effects of removals of animals from a population, and metapopulation dynamics as components of population viability assessment are an important part of small population and threatened species management planning. They provide a quantitative summary of the conservation status of the populations, the interaction of multiple variables on population viability, and permit simulation for evaluation of the effects of proposed management plans on long-term survival of the populations and retention of genetic diversity. We are indebted for much of the following discussion and explanatory material on the modeling process and on VORTEX to the report from the Leontopithecus II PHVA workshop conducted in Belo Horizonte during 20-22 May 1997. The version of VORTEX used in the muriqui workshop was 8.03 rather than 7.41 used in the tamarin workshop so additional descriptive material on this current version is provided.

The objective of this working group was to develop a series of baseline models for the two proposed taxa of *Brachyteles* which could be used to assist evaluation of the objectives, management recommendations, and priorities developed by the other working groups. The development of tools and scenarios for the integration of the local human demographic impacts on the population viability was included with the participation of members of the CBSG human demographic working group in several of the muriqui working groups. Detailed human demographic information for villages around several of the protected areas was collected from literature sources before the workshop. This information provided a basis for projection of possible human impacts on the protected areas and for translation into impacts on the local muriqui population demographic parameters. For example, this approach might allow a more explicit projection of the time course of local hunting effects on the muriqui population dynamics and the risk of extinction. Similar scenarios might be developed for projected timber harvesting on private lands with muriqui populations.

During the workshop several types of scenarios were examined: study of survival and gene diversity loss of hypotheitical muriqui populations of various size from 10 (one group) to 500 individuals; overall survival and maintenance of genetic diversity within and among populations of the two proposed taxa of *Brachyteles* under different rates of translocation among the populations; the level of hunting removal of adult females required to maintain the populations levels at observed low densities in habitats with possible much larger carrying capacities; examination of the effects of removal of animals from a stable or growing population for translocation to establish a new population in unoccupied habitat; and evaluation of the total managed population size required to reach the management goals for survival and retention of genetic diversity for 100 years for each of the two taxa; integration of the human demographic projections into the muriqui population projections for two of the populations. Immediately after the workshop, additional scenarios were modeled and the number of simulations (iterations) run were increased to 500 for each scenario to provide adequate statistical evaluation of the model outputs.

Background – Modeling and Population Viability Assessment

A model is any simplified representation of a real system. We use models in all aspects of our lives, in order to: 1) extract the important trends from complex processes, 2) permit comparison among systems, 3) facilitate analysis of causes of processes acting on the system, and 4) make predictions about the future. A complete description of a natural system, if it were possible, would often decrease our understanding relative to that provided by a good model, because there is "noise" in the system that is extraneous to the processes that we wish to understand. For example, the typical representation of the growth of a wildlife population by an annual percent growth rate is a simplified mathematical model of the much more complex changes in population size. Representing population growth as an annual percent change assumes constant exponential growth ignoring the irregular fluctuations as individuals are born or immigrate, and die or emigrate. For many purposes, such a simplified model of population growth is very useful, because it captures the essential information we might need regarding the average change in population size, and it allows us to make predictions about the future size of the population. A detailed description of the exact changes in numbers of individuals, while in theory, a true description of the population, would often be of much less value because the essential pattern would be obscured, and it would be difficult or impossible to make predictions about the future population size.

In considerations of the vulnerability of a population to extinction, as is so often required for conservation planning and management, the simple model of population growth as a constant annual rate of change is inadequate for our needs. The fluctuations in population size that are omitted from the standard ecological models of population change can cause population extinction, and therefore are often the primary focus of concern. In order to understand and predict the vulnerability of a wildlife population to extinction, we need to use a model which incorporates the processes which cause fluctuations in the population, as well as those which control the long-term trends in population size (Shaffer 1981). Many processes can cause fluctuations in population size; variation in the environment (such as weather, food supplies, and predation), genetic changes in the population (such as genetic drift, inbreeding, and response to natural selection), catastrophic effects (such as disease epidemics, floods and droughts), decimation of the population or its habitats by humans, the chance results of the probabilistic events in the lives of individuals (sex determination, location of mates, breeding success, survival), and interactions among these factors (Gilpin and Soulé 1986).

Models of population dynamics which incorporate causes of fluctuations in population size in order to predict probabilities of extinction, and to help identify the processes which contribute to a population's vulnerability, are used in "Population Viability Analysis" (PVA) (Lacy

1993/1994). For the purpose of predicting vulnerability to extinction, any and all population processes that impact population dynamics can be important. Much analysis of conservation issues is conducted by largely intuitive assessments by biologists with experience with the system. Assessments by experts can be valuable, and are often contrasted with "models" used to evaluate population vulnerability to extinction. Such a contrast is not valid, however, as any synthesis of facts and understanding of processes constitutes a model, even if it is a mental model within the mind of the expert and perhaps only vaguely specified to others (or even at the conscious level to the experts to themselves).

A number of priorities of the problem of assessing vulnerability of a population to extinction make it difficult to rely on mental or intuitive models. Numerous processes impact population dynamics and many of the factors interact in complex ways. For example, increased fragmentation of habitat can make it more difficult to locate mates, can leads to greater mortality as individuals disperse greater distances across unsuitable habitat, and can lead to increased inbreeding which in turn can further reduce ability to attract mates and to survive. In addition, many of the processes impacting population dynamics are intrinsically probabilistic, with a random component. sex determination, disease, predation, mate acquisition – indeed almost all events in the life of an individual – are stochastic events, occurring with certain probabilities rather than with absolute certainty at any given time. The consequences of factors influencing population dynamics are often delayed for years or even generations. With a long-lived species, a population might persist for 20 to 40 years beyond the emergence of factors that ultimately cause extinction. Humans can synthesize mentally only a few factors at a time, most people have difficulties assessing probabilities intuitively, and it is difficult to consider delayed effects (Klein 1998). Moreover, the data needed for models of population dynamics are often very uncertain. Optimal decision-making when data are uncertain is difficult, as it involves correct assessment of probabilities that the true values fall within certain ranges, adding yet another probabilistic or chance component to the evaluation of the situation.

The difficulty of incorporating multiple, interacting, probabilistic processes into a model that can utilize uncertain data has prevented (to date) development of analytical models (mathematical equations developed from theory) which encompass more than a small subset of the processes known to affect wildlife population dynamics. It is possible that the mental models of some biologists are sufficiently complex to predict accurately population vulnerabilities to extinction under a range of conditions, but it is not possible to assess objectively the precision of such intuitive assessments, and it is difficult to transfer that knowledge to other s who need also to evaluate the situation. Computer simulation models have increasingly been used to assist in PVA modeling. Although rarely as elegant as models framed in analytical equations, computer simulation models can be well suited for the complex task of evaluating risks of extinction. Simulation models can include as many factors that influence population dynamics as the modeler and the user of the model want to assess. Interactions between processes can be modeled, if the nature of the interactions can be specified. Probabilistic events can be easily simulated by computer programs, providing output that gives both the mean expected result and the range or distribution of possible outcomes. In theory, simulation programs can be used to build models of population dynamics that include all the knowledge of the system which is available to experts. In practice, the models will be simpler, because some factors are judged more unlikely to be important, and because the persons who developed the model did not have access to the full array of expert knowledge.

Although computer simulation models can be complex and confusing, they are precisely defined and all of the assumptions and algorithms can be examined. Therefore, the models are objective, testable, and open to challenge and improvement. PVA models allow use of all available data on the biology of the taxon, facilitate testing of the effects of unknown or uncertain data, and expedite the comparison of the likely results of various possible management options.

PVA models also have weaknesses and limitations. A model of the population dynamics does not define the goals for conservation planning. Goals, in terms of population growth, probability of persistence, number of extant populations, genetic diversity, or other measures of population performance must be defined by the management authorities before the results of population modeling can be used. Because the models incorporate many factors, the number of possibilities to test can seem endless, and it can be difficult to determine which of the factors that were analyzed are most important to the population dynamics. PVA models are necessarily incomplete. We can model only those factors which we understand and for which we can specify the parameters. Therefore, it is important to realize that the models probably underestimate the threats facing the population. Finally, the models are used to predict the long-term effects of the processes currently acting on the population. Many aspects of the situation could change radically within the time span that is modeled. Therefore, it is important to reassess the data and model results periodically, with changes made to the conservation programs as needed.

Dealing with Uncertainty

It is important recognize that uncertainty regarding the biological parameters of a population and its consequent fate occurs at several levels and for independent reasons. Uncertainty can occur because the parameters have never been measured on the population. Uncertainty can occur because limited field data have yielded estimates with potentially large sampling error. Uncertainty can occur because independent field studies have generated discordant estimates. Uncertainty can occur because environmental conditions or population status have been changing over time, and field surveys were conducted during periods which may not be representative of long-term averages. Uncertainty can occur because the environment will change in the future, so that measurements made in the past may not accurately reflect future conditions.

Sensitivity testing is necessary to determine the extent to which uncertainty in input parameters results in uncertainty regarding the future fate of the population. If alternative plausible parameter values result in divergent predictions for the population, then it is important to try to resolve the uncertainty with better data. Sensitivity of population dynamics to certain parameters also indicates that those parameters describe factors which could be critical determinants of population viability. Such factors are therefore good candidates for efficient management actions designed to assure the persistence of the population.

The above kinds of uncertainty should be distinguished from several more sources of uncertainty about the future of the population. Even if long-term average demographic rates are known with precision, variation over time caused by fluctuating environmental conditions will cause uncertainty in the fate of the population at any given time in the future. Such environmental variation should be incorporated into the model used to assess population dynamics and will generate a range of possible outcomes (perhaps represented as a mean and standard deviation) from the model. In addition, most biological processes are inherently stochastic, having a random component. The stochastic or probabilistic nature of survival, sex determination, transmission of genes, acquisition of mates, reproduction, and other processes preclude exact determination of the future state of a population. Such demographic stochasticity should also be incorporated into a population model, because such variability both increases our uncertainty about the future and can also change the expected or mean outcome relative to that which would result if there was no such variation. Finally, there is "uncertainty" which represents the alternative actions or interventions which might be pursued as a management strategy. The likely effectiveness of such management options can be explored by testing alternative scenarios in the model of population dynamics, in much the same way that sensitivity testing is used to explore the effects of uncertain biological parameters.

Vortex Population Viability Assessment Model

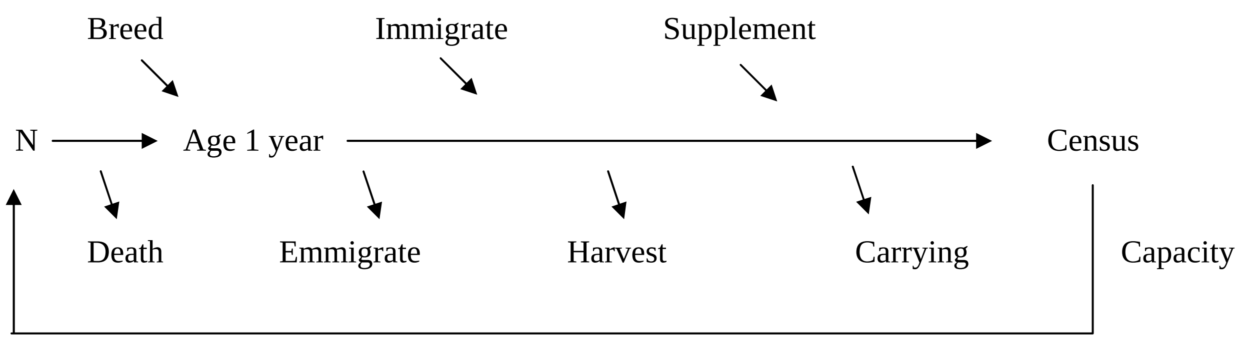
For the analyses presented here, the VORTEX computer software (Lacy 1993) for population viability analysis was used. VORTEX models demographic stochasticity (the randomness of reproduction and deaths among individuals in a population), environmental variation in the annual birth and death rates, the impacts of sporadic catastrophes, and the effects of in breeding in small populations. VORTEX also allows analysis of the effects of losses or gains in habitat, harvest or supplementation of populations, and movement of individuals among local populations.

Density dependence in mortality is modeled by specifying a carrying capacity of the habitat. When the population size exceeds the carrying capacity, additional mortality is imposed across all age classes to bring the population back down to the carrying capacity. The carrying capacity can be specified to change linearly over time, to model losses or gains in the amount or quality of habitat. Density dependence in reproduction modeled by specifying the proportion of adult females breeding each year as a function of the population size.

VORTEX models loss of genetic variation in populations, by simulating the transmission of alleles from parents to offspring at a hypothetical genetic locus. Each animal at the start of the simulation is assigned two unique alleles at the locus. During the simulation, VORTEX monitors how many of the original alleles remain within the population, and the average heterozygosity and gene diversity (or "expected heterozygosity") relative to the starting levels. VORTEX also monitors the inbreeding coefficients for each animal, and can reduce the juvenile survival of inbred animals to model the effects of in breeding depression.

VORTEX is an *individual-based* model. That is VORTEX creates a representation of each animal in its memory and follows the fate of the animal through each year of its lifetime. VORTEX keeps track of the sex, age, and parentage of each animal. Demographic events (birth sex determination, mating, dispersal, and death) are modeled by determining for each animal in each year of the simulation whether any of the events occur. Events occur according to the specified age and sex-specific probabilities. Demographic stochasticity is therefore a consequence of the uncertainty regarding whether each demographic event occurs for any given animal.

Timeline of the VORTEX simulation model



Arrows from above are events that increase N
Arrows away from the line are events that decrease N

Vortex requires lots of population-specific data, rather than using ecological theory to generate many parameters describing population processes. For example, the user must specify the amount of annual variation in each demographic rate caused by fluctuations in the environment. In addition, the frequency of each type of catastrophe (drought, flood, epidemic disease) and the effects of the catastrophes on survival and reproduction must be specified. Rates of migration (dispersal) between each pair of local populations are specified, rather than being assumed to be a simple function of distance or other parameters. Because VORTEX requires specification of many biological parameters, it is not necessarily a good model for the examination of population dynamics that would result from some generalized life history. It is most usefully applied to the analysis of a specific population in a specified environment.

Further information on VORTEX is available in Appendix III (Lacy (1993)) and Lindenmayer et al. (1995) and at internet site : http://www2.netcom.com/~rlacy/vortex.html

Basic Information on *Brachyteles arachnoides*

Items for discussion

1) Carrying capacity
2) Management of population genetic variation
3) Taxonomy
4) Studies of disease

Taxonomy (3 above):

1) Inventory areas of occurrence, considering population information of fauna, including predation, as well as characterizing vegetation. Use playbacks as a method.

2) Special attention should be paid to areas of transition between between the hypothetical species, with a possible geographic limit from southern Rio de Janeiro to Espirito Santo, considering the possible geographic barriers of the Rio Paraiba do Sul.

3) For the states of Sao Paulo and Minas Gerais, the inventories should be made with strategic samples from the extremes of known populations distribution.

4) From the inventory, where data on morphology of the animals to genetics (from faces and/or blood), analyze the genetic structure of the populations.

5) With the creation of a Muriqui Committee, the data obtained from the inventories and morphogenetic analyses will be evaluated with respect to the taxonomy question.

Management of Population Genetic Variation (2 above):

1) Different management is needed for northern and southern populations, with each situation's specific conditions considered.

2) The CPRJ captive breeding program is important , with the objective of studies and reproduction of the species and /or animals to form new colonies Brazil and/or the exterior.

3) Increase fragmented areas to improve the carrying capacity of existing populations.

4) Different strategies are necessary for different populations following the system below:

Low Population Density in Fragmented Areas			
Protection against hunting only	Protection against fragmentation only	Protection for both	Unprotected
High Population Density in Fragmented Forests			
Protection against hunting only	Protection against fragmentation only	Protection for both	Unprotected
Low Population Densities in Large Forests			
Protection against hunting only	Protection against fragmentation only	Protection for both	Unprotected
High Population Density in Large Forests			
Protection against hunting only	Protection against fragmentation only	Protection for both	Unprotected
Absence of muriquis in areas of good quality habitat preferentially protectd			

5) Reintroduction versus translocation: we suggest that translocation is preferable, based on the *Leontopithecus* example.

<u>Informacoes basicas sobre *Brachyteles arachnoides*</u>

Itens para discussao:

1) Capacidade de suporte
2) Manejo de varibilidade genetica populacional
3) Taxonomia da especie
4) Estudos de doencas

Item Taxonomia da especie: metas:

1) Inventario das areas de ocorrencia da especie, considerando as informacoes das populacoes dos animais, incluindo predadores, bem como a caracterizacao da vegetacao; uso de playback como metodologia;

2) Atencao especial para as areas da provavel transicao entre as especies hipoteticas, tendo uma possivel delimitacao geografica a partir do sul do Rio de Janeiro ate o Espirito Santo, levando em consideracao a possivel barreira geografica do Rio Paraiba do Sul.

3) Para os estados de Sao Paulo e Minas Gerais, os inventarios deverao ser feitos por amostragens estrategicas dos extremos de ocorrencia da distribuicao das populacoes conhecidas.

4) A partir das informacoes dos inventarios, onde serao obtidos dados da morfologia dos animais, bem como informacoes geneticas (a partir das fezes e/ou sangue), serao feitas as analises de estrutura genetica das populacoes.

5) A partir da criacao de um Comite do Muriqui, os dados obtidos nos inventarios e analises morfogeneticas serao avaliados quanto a questao taxonomica.

Item: Manejo da variabilidade genetica:

1) Manejo diferenciado das populacoes da regiao norte e da regiao sul, levando-se em consideracao as particularidades de cada situacao;

2) Importancia da criacao da especie em cativeiro (CPRJ), com o objetivo de estudos e reproducao do muriqui, para fornecimento de animais para a formacao de novas colonias no Brasil e/ou no exterior;

3) Importancia de ampliacao das areas fragmentadas, para ampliar a capacidade de suporte das populacoes existentes;

4) Diferentes estrategias de manejo para as diferentes situacoes populacionais existentes, conforme o esquema abaixo:

populacao com baixa densidade,
em areas fragmentadas

protegidas contra caca apenas	protegidas contra desmatamento apenas	protegidas para ambos	nao protegidas

populacao com alta densidade,
em areas fragmentadas

protegidas contra caca apenas	protegidas contra desmatamento apenas	protegidas para ambos	nao protegidas

populacao com baixa densidade,
em areas grandes

protegidas protegidas protegidas nao protegidas
contra caca contra desmatamento para ambos
apenas apenas

populacao com alta densidade,
em areas grandes

protegidas protegidas protegidas nao protegidas
contra caca contra desmatamento para ambos
apenas apenas

inexistencia de populacao de muriquis,
em areas com habitats de boa qualidade e suporte,
preferencialmente protegidas

5) Reintroducao x Translocacao da especie; sugestao de que seja translocacao, tendo por base o exemplo dos mico-leoes.

Wild Population Model Input Parameters

Muriquis have been studied at a number of sites, but long-term data on their life history and reproductive parameters are only available from one study group at the Estacao Biologica de Caratinga, Minas Gerais. The forest supports 2-3 groups of muriquis in addition to large populations of three other primate species. The main muriqui study group has been monitored systematically since 1982 as part of an ongoing study of muriqui behavioral ecology and reproduction (Strier, 1992; In press). All members of the study group are recognized individually from their natural markings, permitting us to accompany individual life histories.

Data collected from 1982-1993 were compiled for a preliminary PVA using Vortex v. 6 (Strier, 1993-1994). The study group was treated as a single population, and known life history, reproductive, and ecological variables were used to evaluate the viability of the population under various simulated conditions. Low mortality rates, the female-biased infant sex ratio, and expanding habitat contributed to the low extinction probabilities that emerged from this analysis. Furthermore, there were no visible effects of inbreeding depression during the 100 years that the simulation was run.

The present PVA employs Vortex v. 8.03 and data obtained from 1993-1997 (Strier, In press) to update our perspectives on the viability of this population. Additional simulations for the captive population at the Centro de Primatologia de Rio de Janeiro (Pissinati, et al., In press) and modified variables that may be relevant for other wild populations are included.

Estacao Biologica de Caratinga Muriquis

The population was simulated using the expanded 1982-1997 database for the main study group. The population was simulated for 200 years to assess whether the original absence of significant effects of inbreeding depression was a consequence of the long generation lengths (roughly 20 years) that would amount to only 5 generations in the 100 year simulation. Even with 200 year simulations, however, inbreeding had no significant effect on final extinction probabilities or population size. Behavioral data also indicate that muriquis avoid close inbreeding (Strier, 1997). Therefore, 100 year simulations were used in the following analyses, with 200 iterations. Extinction was defined as no animals of one or both sexes, and no inbreeding depression was modeled.

The study group had increased from 51 individuals in 1993 to 63 individuals by 1997 (Strier, In press), although we estimate that the current population includes at least 90-100 individuals (Strier and Fonseca, In press). The 1993 group size and age-sex class composition were used as the starting population in our current PVA.

Female age of first reproduction = 9 years.
Previously, simulations were run with values of 7 and 11 years based on age at first reproduction for one female who reproduced in her natal group and the estimated age of first reproduction for immigrant females (Strier, 1996).

Male age of first reproduction = 7 years.
The onset of sexual activity in males in this population ranges frm 5.5-9.5 years (Strier, 1997). We do not whether the probability of fertilization increases with age, but males in captivity are capable of fertilizing females at much younger ages, years before they exhibit sexual activity in this wild population (Pissinati, et al., In press).

Maximum breeding age (senescence) = 35 years.
See rationale in Strier (1993-1994).

Sex ratio at birth = 0.356.
This value is updated with data representing a total of 56 infant births (Strier, In press).

Mating system = Polygynous, with all adult males in the breeding pool.
Despite individual differences in mating frequencies, all males in the study group copulated, and group females copulated with group males as well as males from another muriqui group in this forest (Strier, 1997).

Proportion of females breeding = 26.50% (Standard deviation due to environmental variation = 12.40%)
This value is updated based on modifications in the more recent version of Vortex using actual data on the proportion of females that reproduced each year from 1983-1997. Muriqui interbirth intervals average 3 years (Strier, 1996). The average proportion of breeding females each year is slightly lower than 33% due both to the inclusion of recent immigrant females that had not yet begun to reproduce and instances in which females failed to reproduce in their third year post-partum. Interbirth intervals were shorter when infants died prior to weaning than when infants survived (Strier, In press).

Litter size = 1.
Maximum litter size was previously considered to be 2 based on a single set of twins born in

1986 (Strier, 1991). However, the fact that all of the other 55 births from 1983-1997 have been of single infants leads us to conclude that twins are highly unusual in this species.

Mortality rates were updated from the previous PVA to incorporate more recent mortalities of 13 month old infants due to suspected predations (Printes, et al., 1996) and some additional adult mortalities. Age-specific mortalities for both sexes were calculated from individual records of infants of known age. Mortality rates for these individuals as they reach adulthood are lumped with those of adults of unknown age that were present in the group at the onset of study. Adult mortality rates are calculated by summing the number of adults of each sex each year over the number of years (1982-1997) of the study to date. See Strier (In press) for details on all mortalities.

Age class	Females qx	SD(EV)	Males qx	SD(EV)
0-1	0	0	.01	.024
1-2	.057	.028	.056	.028
2-3	0	0	.118	.059
3-4	.036	.018	0	0
4-5	0	0	0	0
5-6	0	0	0	0
6-7	0	0	0	0
7-8	0	0	.0152	.015
8-9	0	0		
>9	.01	.01		

Frequency of type 1 catastrophes = 6.67%
Effect on reproduction =.5; effect on survival =.9. See rationale in Strier (1993-1994).

Frequency of type 2 catastrophes = 5%
The possibility of a drought or other type of catastrophe at 20 year intervals was included in this simulation in an effort to better characterize the original size and age structure of the population, which lacked any females in the age >1-<adult category (Strier, 1991).
Effect on reproduction = 0; effect on survival = 1.0.

Initial population = 51 (as of 1993, when last PVA was conducted):

Age	Males	Females
1	2	2
2	2	6
3	1	1
4	0	2
5	2	1
6	1	3
7	1	0
8	2	1
9	0	0
10	0	5

11	0	0
12	2	2
13	0	0
14	0	0
15	0	1
16	0	1
17	1	0
18	0	0
19	4	8
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0
31	0	0
32	0	0
33	0	0
34	0	0
35	0	0
TOTAL:	18	33

Carrying capacity = 240 individuals
See Strier (1993-1994) for rationale.

SD in K due to EV = 0
Modified from previous PVA because there is no real evidence for major changes in carrying capacity due to environmental variance at this time. The relatively high EV values included in the previous PVA may account for the large fluctuations in population sizes that were obtained in those simulations during the 100 year periods examined.

Havesting or supplementing of population = No

Deterministic population growth = Based on females, with assumptions of:

- No limitation of mates
- No density dependence
- No inbreeding depression

r= 0.056
lambda = 1.057
RO = 2.938
Generation time for females = 19.38 years
Generation time for males = 17.66 years

Probability of Extinction of 200 simulations over 100 years: 0

Mean final population size = 236.41 (0.61 SE; 8.70 SD)

Age	Females	Males
1	12.61	6.86
2	10.56	5.82
3	10.46	4.97
4	9.13	4.64
5	8.57	4.12
6	8.27	4.02
7	8.07	45.47 (Adult)
8	7.33	
9	85.52 (Adult)	
TOT:	160.51	75.89

Across all years, prior to K truncation, mean growth rate (r) = 0.0542 (0.0004 SE; 0.0627 SD)

Final Expected H = 0.9611 (0.0004 SE; 0.0058 SD)
Final Observed H = 0.9670 (0.0009 SE; 0.0122 SD)
Final Number of alleles = 45. 93 (0.29 SE; 4.12 SD)

Simulation Variables and Criteria

Simulations were run under different conditions of starting population size, carrying capacity, adult and infant mortality, inbreeding, sex ratios, and the proportion of females that reproduced annually (Figures 1 – 24).

Discussion of Simulation Models of Wild Populations

The effects of increases in K and in the proportion of males born were similar in the present PVA to those in the previous PVA (Strier, 1993-1994). New findings are summarized below:

1. The effects of starting population size and K on extinction probabilities under most conditions were similar: Larger starting populations could tolerate higher mortality rates, less favorable infant sex ratios, and lower proportions of breeding females than smaller starting populations before reaching extinction probabilities >2-4%. At starting population sizes of 10 individuals, extinction probabilities across all conditions were similar independent of carrying capacity. At

starting population sizes of 50, however, carrying capacity had an effect on extinction probabilities under some conditions. For example, at infant sex ratios of 0.5 and starting populations of 50 individuals, those with a K of 50 exhibited unacceptable extinction probabilities when only 20% of females reproduced each year with adult mortality >5%, whereas populations with a K of 240 under identical conditions did not exhibit high extinction risks until adult mortality exceeded 15%.

2. Adult and infant mortality probabilities had interacting and dramatic effects on population viabilities, particularly in small populations independent of K. For example, at slightly female-biased infant sex ratios, starting populations of 10 and 50 individuals with only 5% infant mortality exhibited high extinction probabilities with only 1% and 5% adult mortality, respectively. In other words, very little adult mortality from causes such as hunting could dramatically increase extinction probabilities if infant mortality reached 5% or higher.

3. The proportion of females breeding each year also affected extinction probabilities. Even a small decline, from 26.5% (observed conditions) to 20% females breeding each year meant that lower adult mortality caused higher extinction probabilities. Thus, with starting populations of 50 individuals, 240 K and 26.5% females breeding per year, populations remained viable with up to 15% adult mortality. With the same starting population size, but only 20% of females breeding annually, populations remained viable with only 10% adult mortality. For small starting populations or lower carrying capacities, only 1% adult mortality led to unacceptable extinction probabilities if interbirth intervals increased to 5 years instead of 3 years.

4. The effects of constant or decreasing carrying capacity were not evident under identical conditions of starting population size, carrying capacity, and infant sex ratios. Nonetheless, lower K values resulted in less tolerance to unfavorable mortality or reproductive conditions than higher K values.

Modeling of the Captive Population

Muriquis Brachyteles arachnoides have been kept at the Rio de Janeiro Primate Centre (CPRJ) since 1987 following the construction of a large cage in 1984, which was financed by Wildlife Preservation Trust International (WPTI) [Coimbra-Filho et al., 1993].

Two subadult females (Ns. 891 and 924) were acquired in January and July 1988, from the state of Minas Gerais. Subsequentely two immature males (Ns. 1012 and 1091) were acquired in May 1989 and January 1990, from Cunha and PETAR (Alto Ribeira State Park), respectively (Coimbra-Filho et al., 1993).

The females obtained from Minas Gerais came from northern populations and the males from southern populations (*Brachyteles arachnoides*).   Pairing of the animals was made in 1989, with the first birth occurrin September 1991.

Desta forma, as femeas obtidas de Minas Gerais pertencem as populacoes do Norte (Brachyteles hypoxanthus) e os machos as populacoes do Sul (Brachyteles arachnoides). O pareamento dos animais foi feito em 1989, com o primeiro nascimento ocorrendo a partir de setembro de 1991.

In the VORTEX simulations, we considered each variety as the same species, with data on the known captive population being used to evaluate its viability with the following criteria:

number of iterations = 100
number of years = 100
number of populations = 1
>Two females were lost to illness, produced 8 infants (4/3/1) over a period of 5 years. Of these infants 3/2 (Pissinatti et al., 1998, in press).

Para a realizacao da simulacao com o programa VORTEX, considerou-se ambas as especies como sendo uma mesma especie, com os dados da populacao conhecida em cativeiro sendo utilizados para a avaliacao de um primeiro modelo de viabilidade da mesma, com as seguintes caracteristicas:

number of iterations = 100
number of years = 100
number of populations = 1
> Houve perda das duas femeas devido a doencas, sendo que as mesmas produziram 8 filhotes (4/3/1), num periodo de 5 anos. Destes filhotes, houve perda de 1/1/1 animais, permanecendo vivos 3/2 (Pissinatti et al., 1998, in press).

Inbreeding depression: no
- The populations are considered two species (or subspecies), inbreeding depression probably does not aoocr. However, the data are still uncertain.
-

> Por serem populacoes que inclusive estao sendo consideradas como especies diferentes, a depressao por endogamia provavelmente nao ocorre. No entanto, os dados sao ainda incipientes.

Number of types of catastrophes = 1 (diseases)

Probability of catastrophes = 5% (1 per 20 years)
> No entanto, considerou-se o nao efeito da catastrofe na reproducao e sobrevivencia dos animais.

Breeding system = polygynous (Strier, 1986, 1987, 1992)
> with all adult males in the breeding pool.

Female age of first reproduction = 4 years

Male age of first reproduction = 2 years

Maximum breeding age = 25 years

sex ratio at birth = 0.45

proportion of females breeding = 80% (SD = 10%)

Litter size = 1

Mortality rate

Age	Females	Males
0-1	37.5 (12.5)	37.5 (12.5)
1-2	0.0	0.0
2-3	0.0	0.0
3-4	0.0	0.0

Initial population = 4

Age	Males	Females
1	2	0
2	0	0
3	0	0
4	0	2

Carrying capacity = 30
>The intention was to create 4 groups, with 2 from each region and a total of 30 individuals to start the captive colony in Brazil. With this, it would be possible to form other captive colonies in Brazil to function as defensive satellites and flagships of conservation to market conserevation.

> Ha a intencao de criacao de 4 grupos, sendo 2 de cada regiao, perfazendo um total de 30 individuos para iniciar a colonia em cativeiro no Brasil. Com isto, possibilitar-se-ia a formacao de outras colonias fora do Brasil, funcionando como colonias satelites (defesa) e como bandeiras de conservacao no marketing conservacionista.

Across all years, mean growth rate (r) = 0.1433 (0.0008 SE; 0.079 SD)

Final expected heterozygosity was = 0.6145 (0.0004 SE; 0.0058 SD)
Final observed heterozygosity was = 0.6487 (0.0134 SE; 0.1344 SD)
Final number of alleles was = 4.07 (0.09 SE; 0.87 SD)
> A minimum heterozygosity to be maintained for reproduction of at least 90%.

> Uma heterozigosidade minima a ser almejada para uma criacao seria a de pelo menos 90%.

SD in K due to EV = 0

Harvesting or supplementing of population = no

Deterministic population growth = based on females, with assumptions of:
no limitation of mates
no density dependence
no inbreeding depression

r = 0.149
lambda = 1.161

RO = 5.455

generation time for females = 11.39 yrs
generation time for males = 9.85 yrs.

Probability of extinction of 100 simulations over 100 years = 0
mean final population size = 30.09 (0.20 SE; 2.04 SD)

Recommendations

I. Estacao Biologica de Caratinga

Maintain and utilize the long-term data from the muriquis at the Estacao Biologica de Caratinga:

A) Identify the criteria necessary to evaluate any future problems with this population that signal the need for rapid management responses.

Based on our PVA, the EBC population appears to be extremely viable for the next 100-200 years under the current favorable conditions of high reproductive rates, extremely low mortality at all age-sex classes, including infants aged 0-2 years, and female-biased infant sex ratios. We recognize this population as a critical resource for monitoring many aspects of the muriqui's biology, including how the population ultimately responds to density dependence effects. Nonetheless, we must be alert to any indication of demographic problems that might lead this population into an extinction vortex, and that could be avoided with proper management and attention. Therefore, we recommend the use of specific criteria to evaluate the status of this population over time.

The population (group) has been increasing in a linear fashion. Deviations from this linearity could be due to any number of factors, including:

a) A decrease in reproductive output due to density dependent effects.

b) Partial or total reproductive failure due to disease.

c) Inbreeding depression.

d) Reproductive senescence.

e) Increases in mortality rates across all age-sex classes or within specific age-sex classes.

Continuous monitoring of the proportion of females that reproduce each year and mortality rates at all age-sex classes, but especially among males and females < 1 year of age and reproductive -aged females will provide the data necessary to identify deviations. Deviations > 2 standard deviations of current values will be interpreted as a signal of potential problems beyond the range of stochastic fluctuations. Deviations > 3 standard deviations of current values will be interpreted as symptomatic of a serious impending population catastrophe that would merit rapid management decisions.

B) Extrapolate from the Caratinga database to evaluate other muriqui populations as census results on the sizes, age and sex structures of other populations become available. These comparisons will be used to determine which populations are at the greatest risk of extinction. High risk populations may be identified as requiring the implementation of management plans, which may include translocations to other wild habitats or to augment the captive breeding population. Although we do not recommend bringing healthy, wild muriquis from protected locations into captivity, we nonetheless recognize that for doomed populations, we face the choice of permitting all members to go extinct, or preserving some members to reinvigorate other populations, including the captive breeding colony.

II. Captive population at the Centro de Primatologia de Rio de Janeiro:

We anticipate that the primary role of the CPRJ for the muriqui will continue to be one of receiving confiscated individuals. We do not, at this point, envision the development of an extensive captive breeding program to be an immediate priority for the species. Captive-bred individuals might be used as ambassadors for attracting zoo or wild animal park funds for conservation efforts in Brazil. Confiscated animals, either from private individuals or from zoos that are not equipped to care for muriquis properly, will continue to form the CPRJ captive population.

Because these individuals tend to arrive at the CPRJ in poor health, they are not ideally suited to developing a strong captive breeding colony. Nonetheless, we seek to improve conditions at the CPRJ for the muriquis that are brought there.

A) Comparisons between the Caratinga and CPRJ populations indicate some important differences. The captive population has exhibited younger ages at first reproduction for both males and females, a higher proportion of reproductive females owing to a shorter interbirth interval compared to wild females, even when infants survive. These factors result in a higher reproductive rate in captivity compared to the wild, even the highly successful Caratinga population. Yet, the captive population has experienced a much higher mortality rate in the age class of 0-1 for both males and females. This high mortality rate could be attributed to a number of factors, which include:

1) The poor quality of life that the females experienced in captivity prior to their arrival at the CPRJ. In particular, the effects of poor nutrition, lack of adequate exercise, etc. are known to cause difficulties in parturition and reduced infant health. In addition, close contact with humans prior to joining the CPRJ may interfer with their natural social and maternal behavior.

2) Currently, the CPRJ muriquis are confined to a small area relative to their group size, which could cause stress or other density-dependent effects that reduce infant survivorship.

To improve infant survivorship, we recommend that additional muriqui enclosures are constructed to accommodate the growing population. Increasing the housing possibilities at the CPRJ will reduce density pressures that may be interfering with infant survivorship.

In addition, we recommend that:

1) The CPRJ population be maintained on a diet as diverse as possible, including natural plant foods that are known to be preferred by muriquis in the wild (e.g., *Apuleia leiocarpa*; *Centrolobium tomentosum*; *Virola* sp.). More studies of their diet and nutrition in the wild and captivity are needed.

2) The personnel involved with caring for the CPRJ muriquis should be highly trained and qualified. In particular, these individuals must be required to maintain high levels of hygiene so as not to risk infecting the muriquis with disease or illness.

By improving the personnel, diets, spacing, housing, and general facilities at the CPRJ, we anticipate continued reproductive success and a reduction in the current levels of infant mortality.

III. Increase information on the demographic status of other muriqui populations

A) Work with the census and management groups to maintain an updated database on the size, composition, and density of other muriqui populations.

B) Stimulate the collection and maintenance of long-term demographic data on other muriqui populations. In particular, populations such as those at the Carlos Botelho-Intervales areas will provide critical comparative perspectives on muriquis living under more "natural" conditions than those at Caratinga.

Simulation Models

Selected results of some of the simulation models are illustrated in Figires 1-24.

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Figure 1. Effect of 4 different levels of adult mortality on the mean population size at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 60, K = 240). The parameter values for the base scenario (file # QUI.002) were based upon the field work of K. Strier at Caratinga.

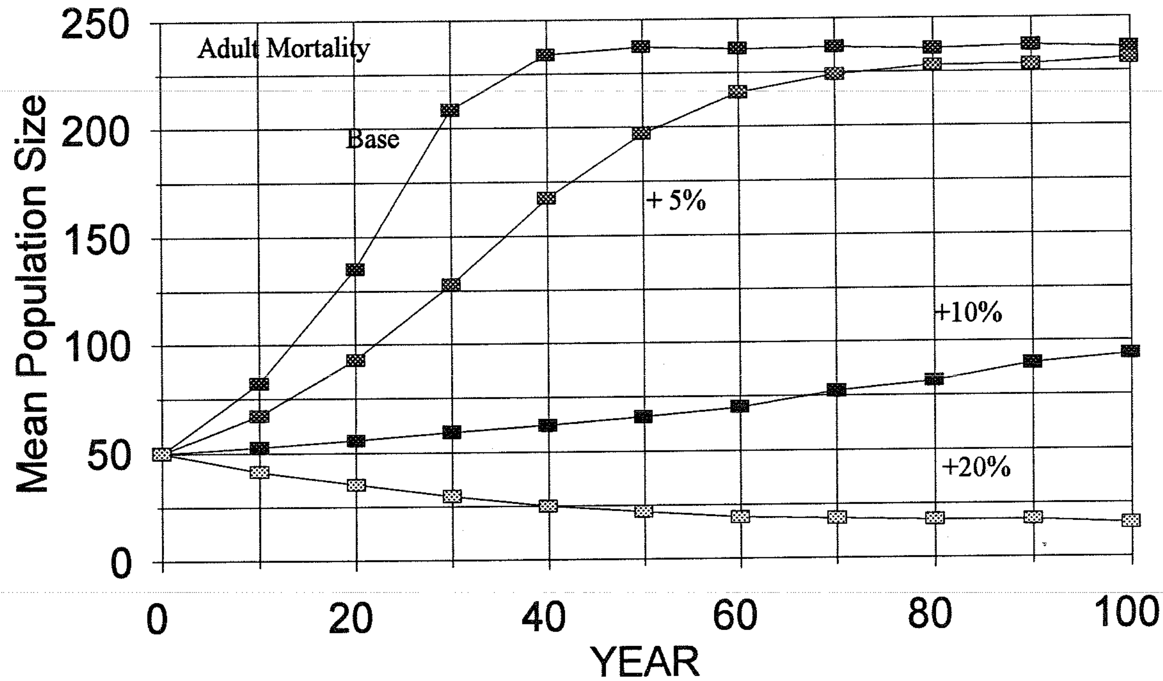


Figure 2. Effect of 4 different levels of infant (0 - 1 year) mortality on the mean population size at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K =240).

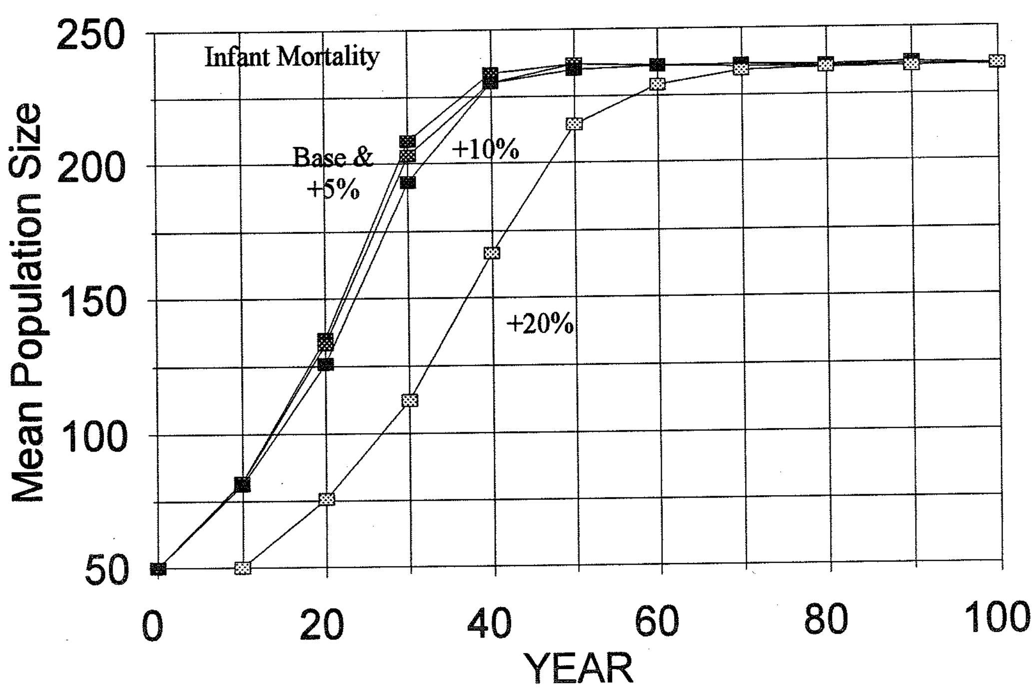


Figure 3.Effect of 4 different levels of adult mortality on the mean remaining heterozygosity at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K =240).

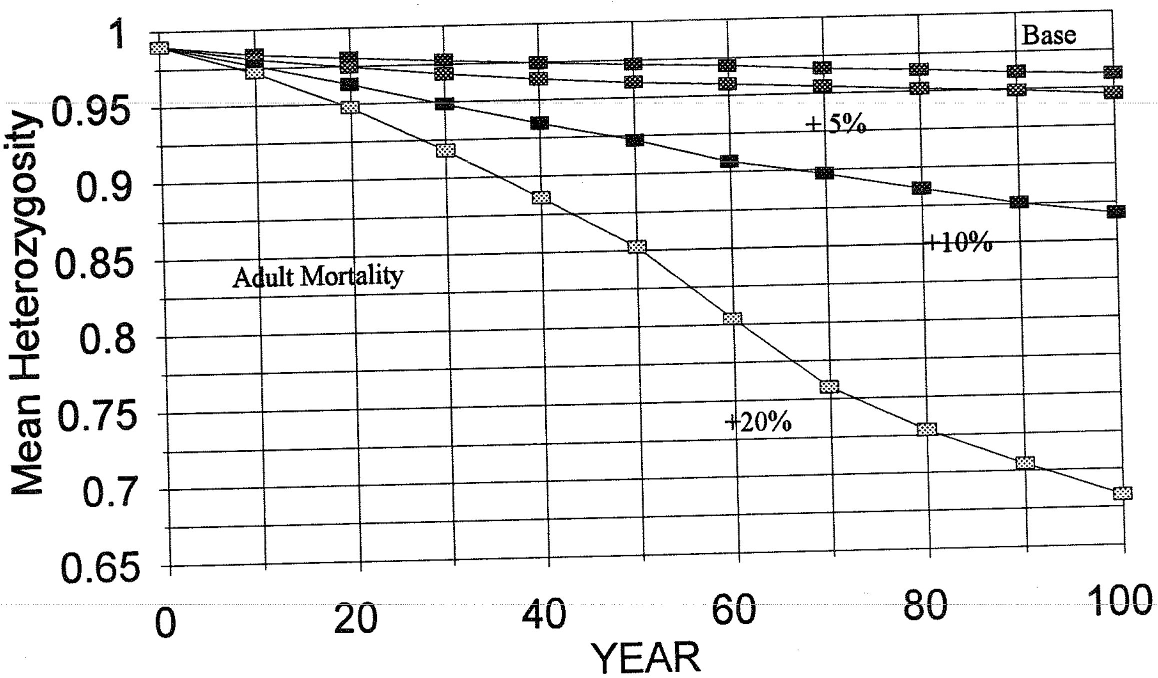
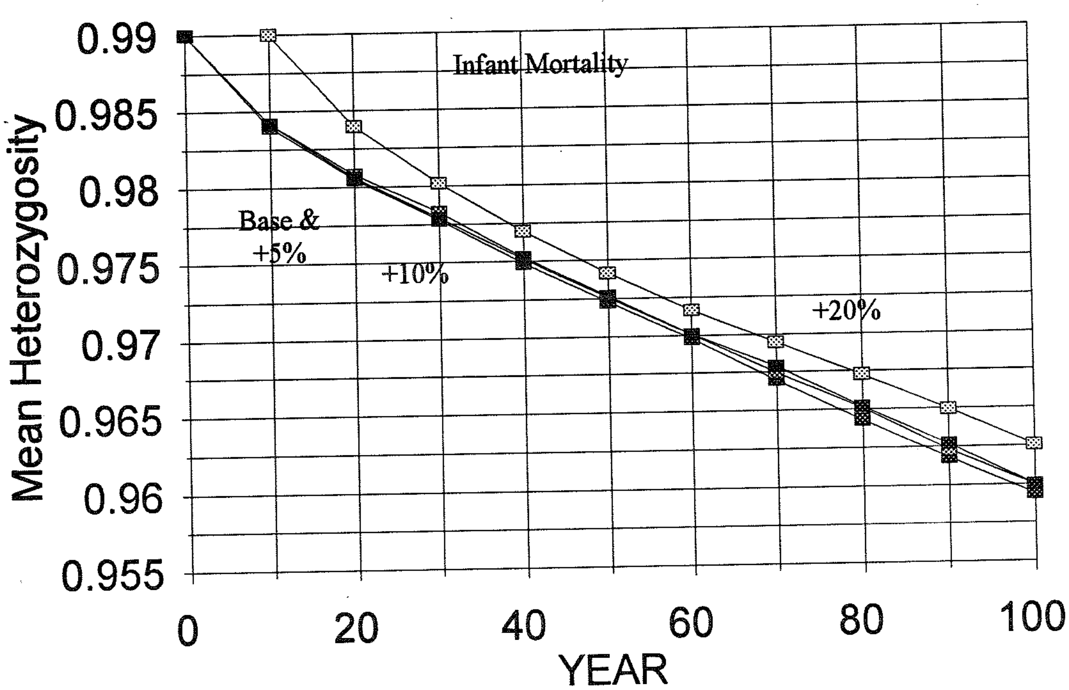


Figure 4. Effect of 4 different levels of infant mortality on the mean remaining heterozygosity at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K =240).



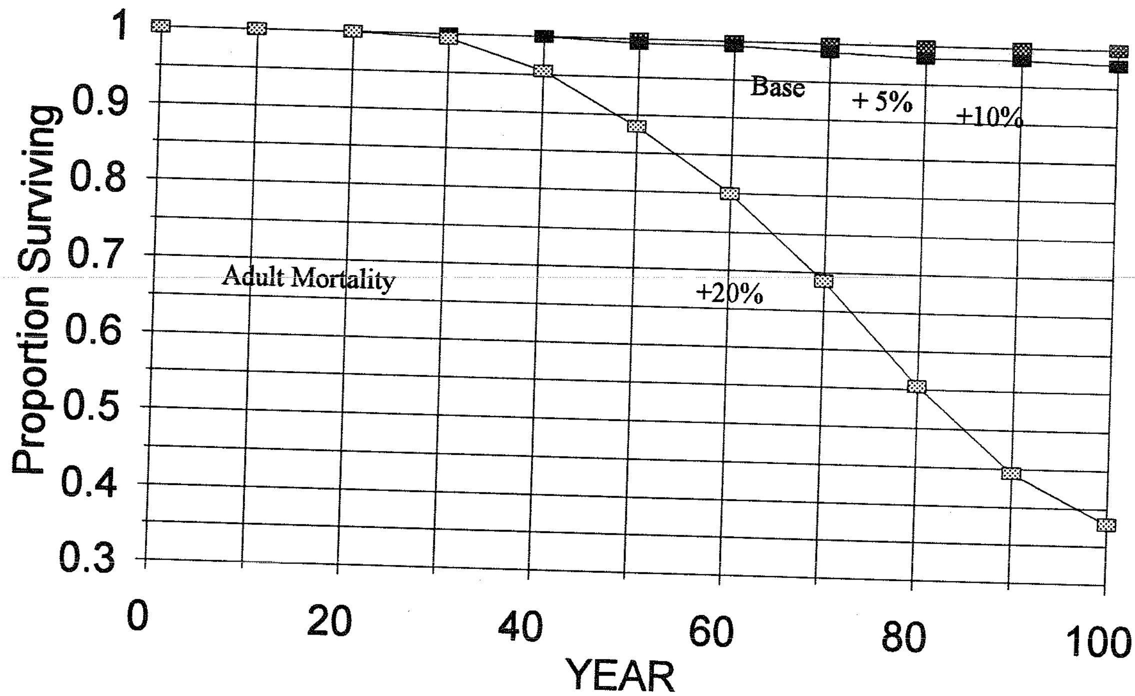


Figure 6. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different levels of adult mortality on the proportion of muriqui populations surviving at 10 year intervals o[illegible]
are as in the base scenario.

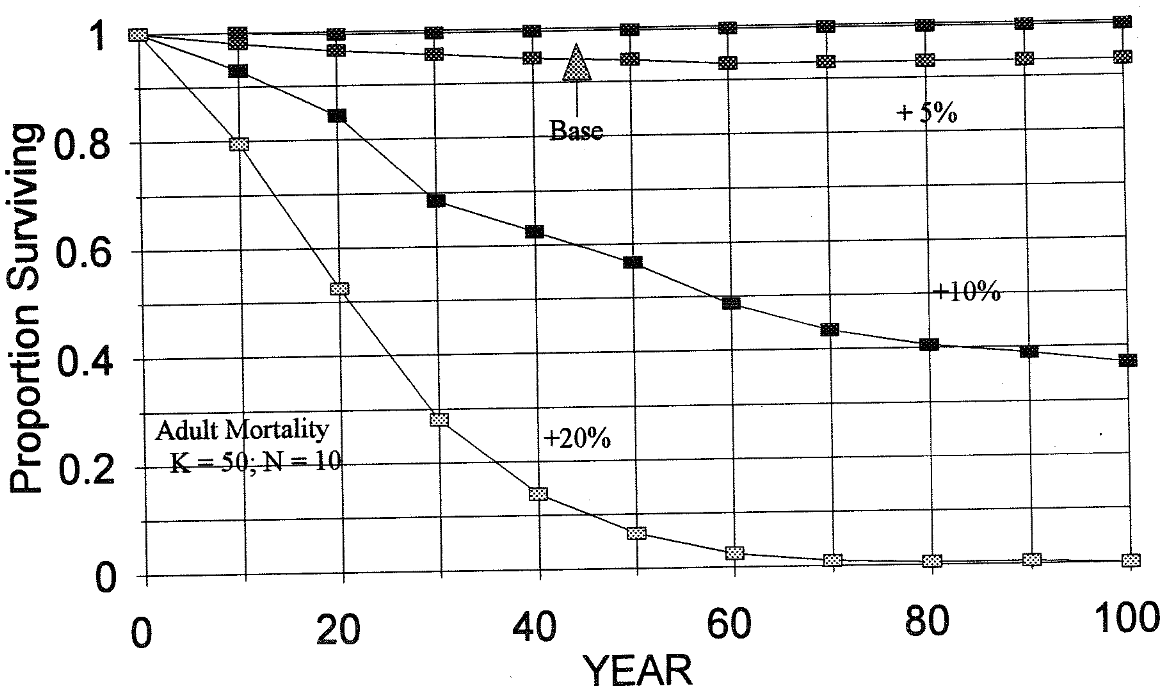


Figure 7. Effect of 2 levels of inbreeding depression on the mean population size at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K = 240). No effects were observed under these conditions.

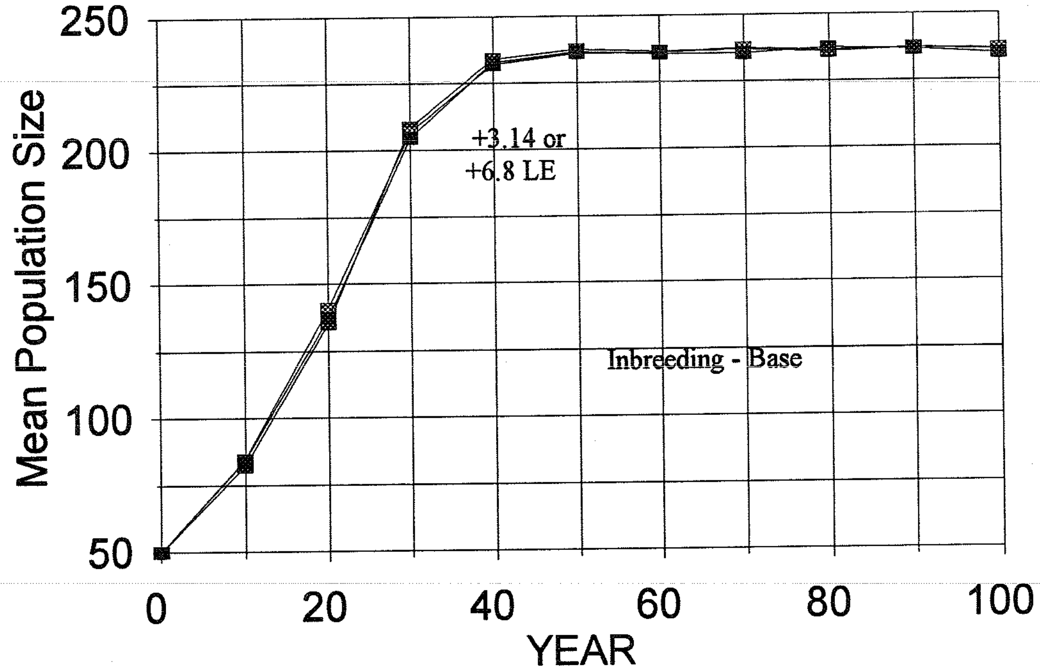


Figure 8. Effect of 2 levels of inbreeding depression on the mean remaining heterozygosity at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K = 240). No effects were observed under these conditions.

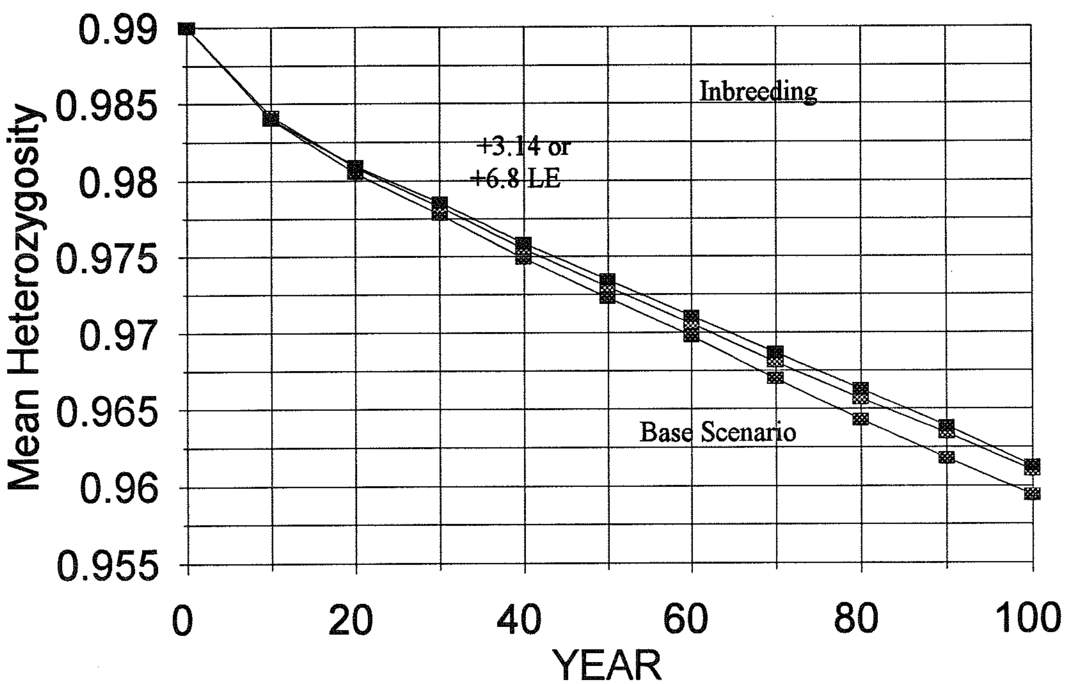


Figure 9. Effect of 3 male/female sex ratios at birth on the mean population size at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K = 240). [illegible] different growth rates reflect the different numbers of breeding females in the respective [illegible]

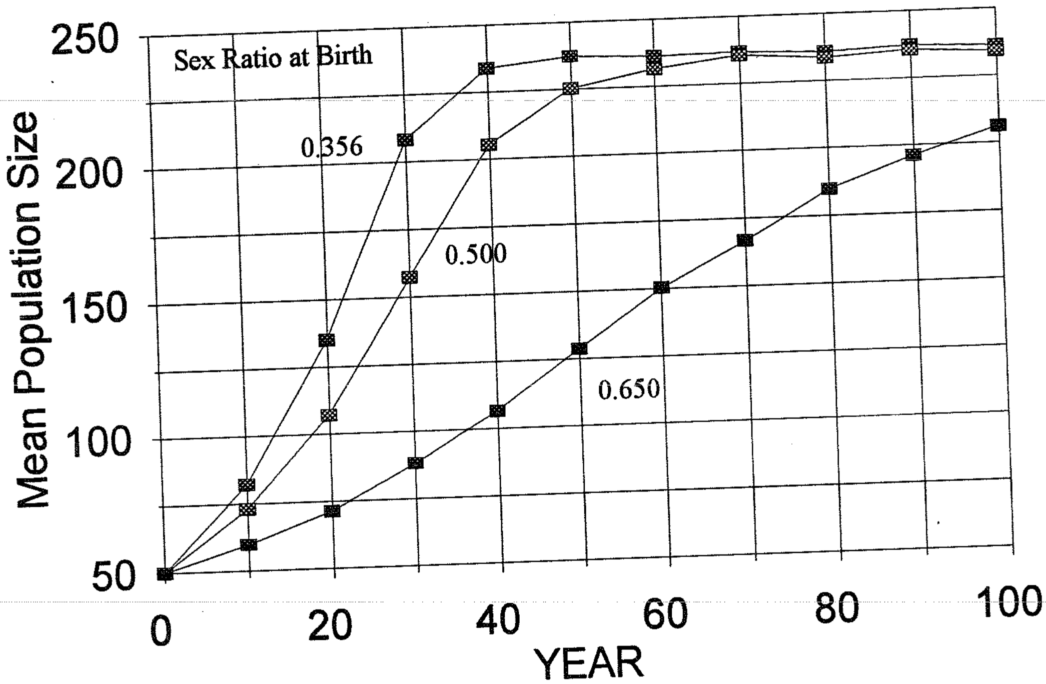


Figure 10. Effect of 3 male/female sex ratios at birth on the mean remaining heterozygosity at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K = 240).

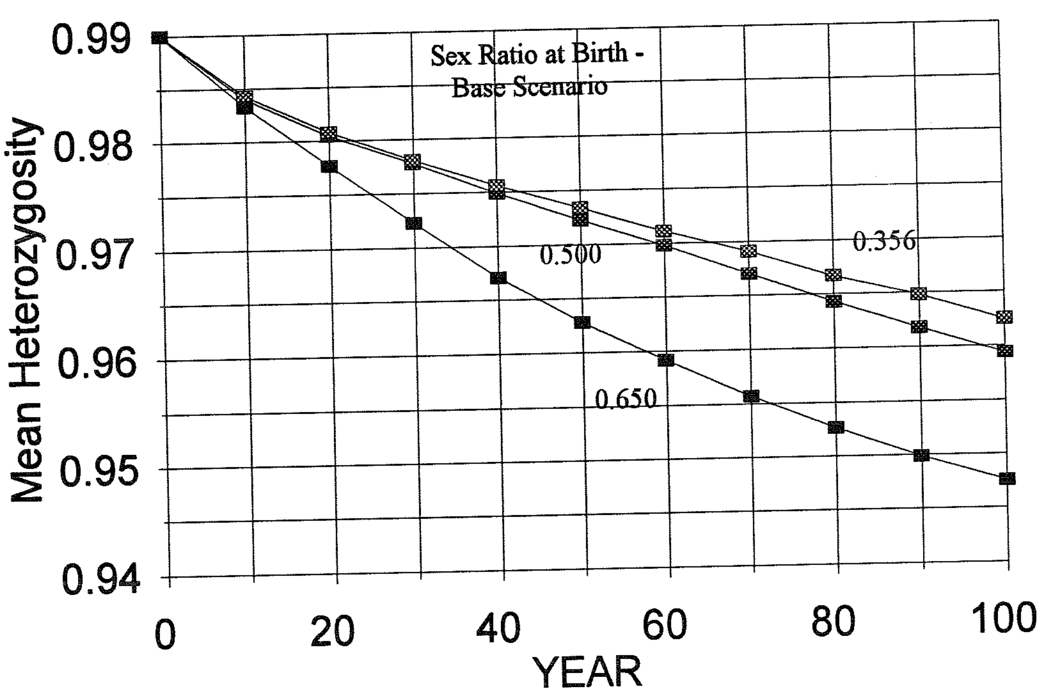


Figure 11. Effect of 3 different proportions of females breeding each year (mean interbirth interval) the mean population size at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K = 240).

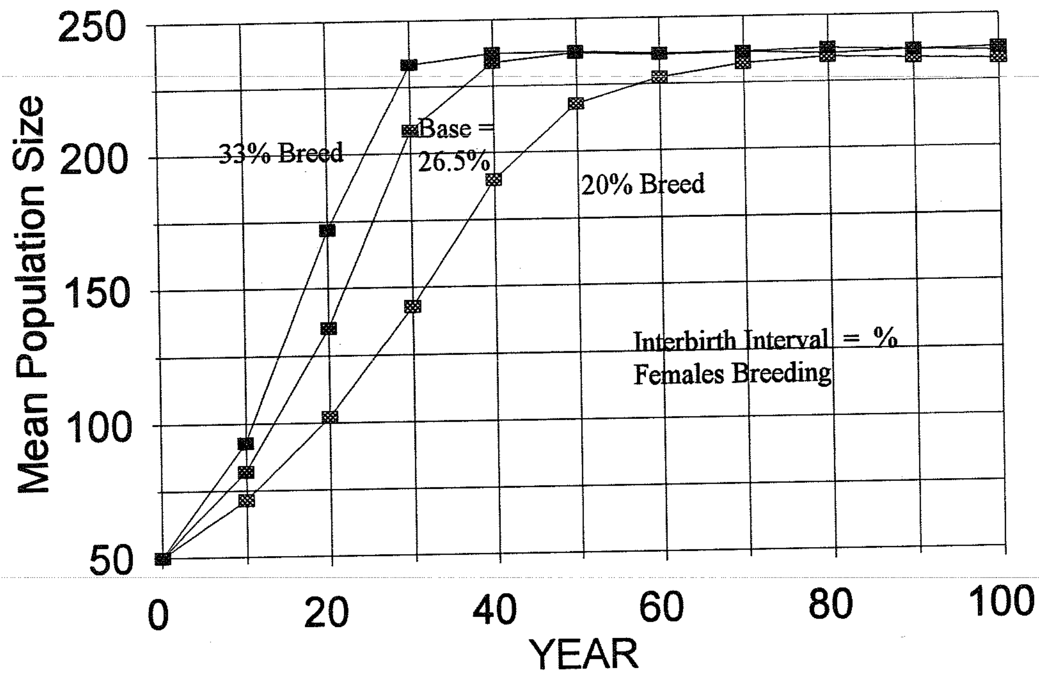


Figure 12. Effect of 3 different proportions of females breeding each year (mean interbirth interval) the mean remaining heterozygosity at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, K = 240).

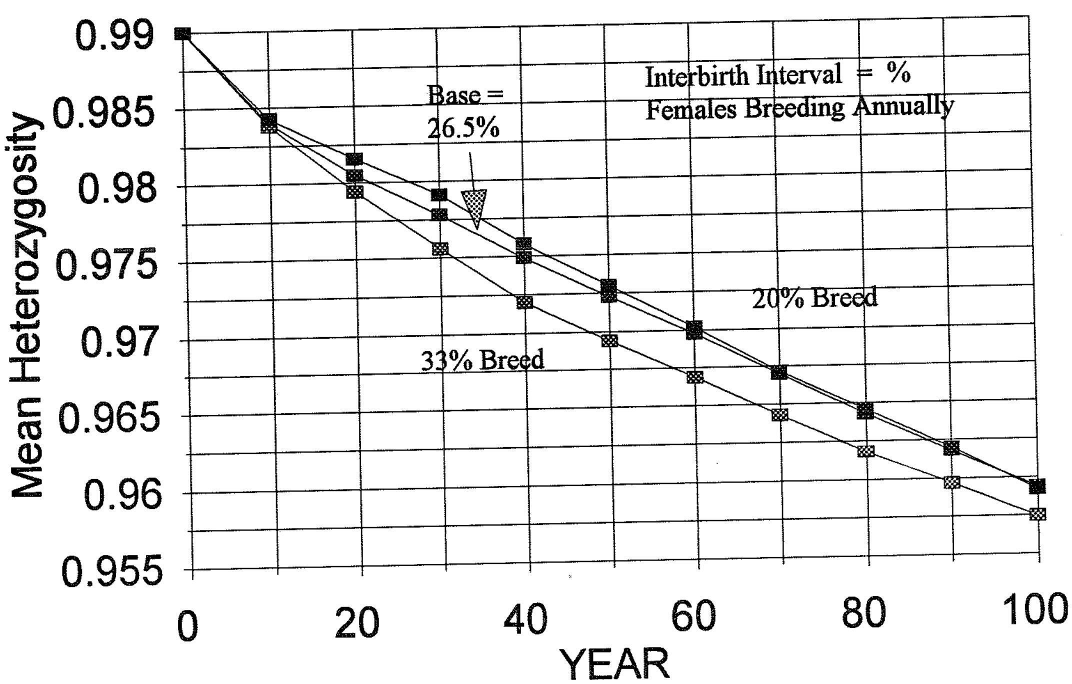
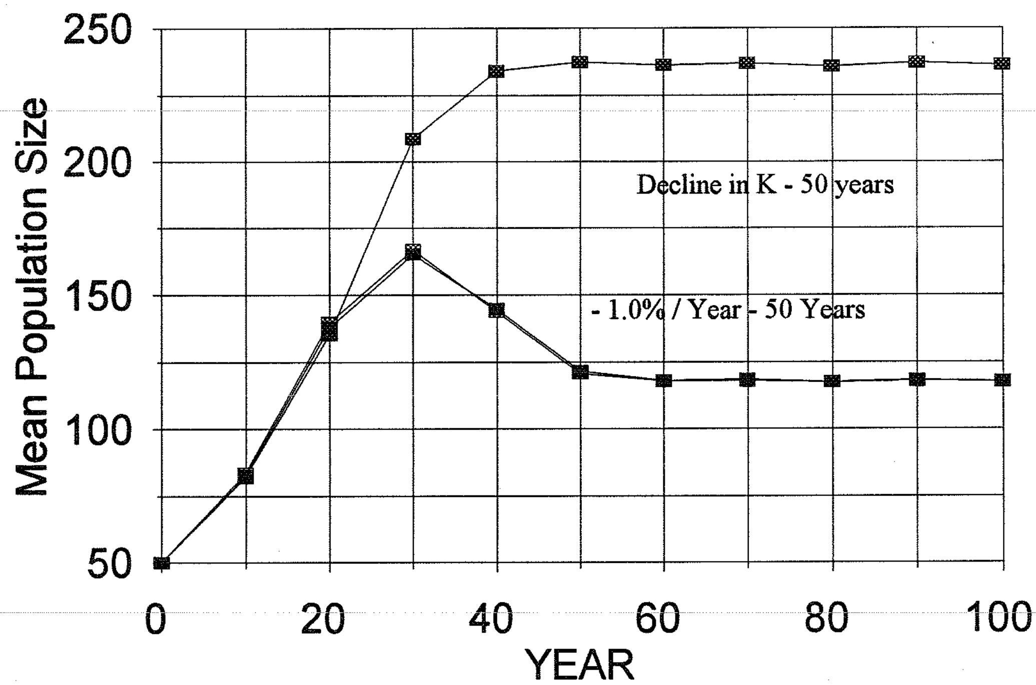


Figure 13. Effect of a 1% per year decline in K for 50 years on the mean population size at 10 year intervals of a muriqui population over 100 years. All other parameter values are as in the base scenario (starting N = 50, starting K = 240, final K = 120).



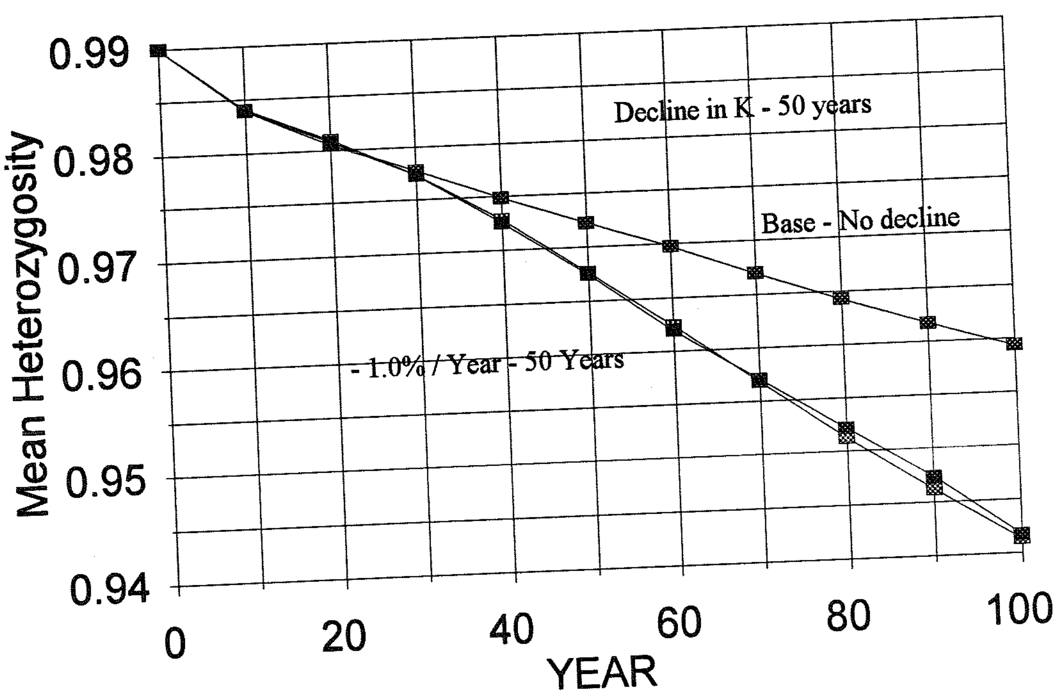


Figure 15. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different levels of adult mortality on the mean muriqui population size at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

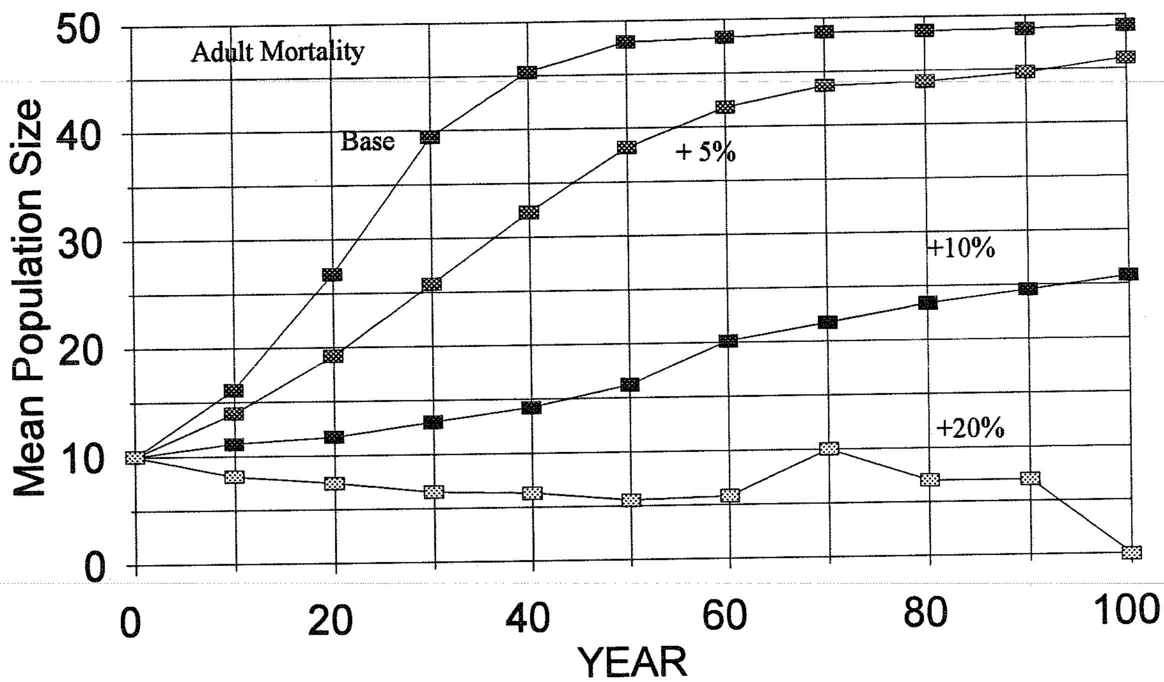


Figure 16. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different levels of adult mortality on the mean remaining heterozygosity at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

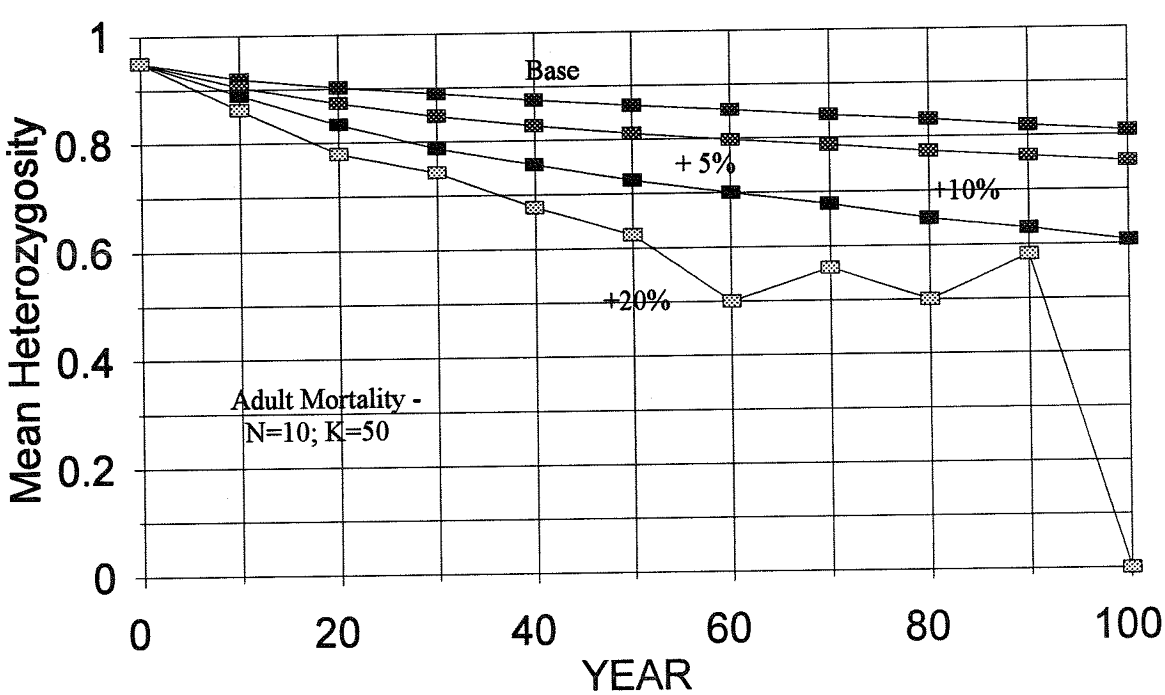


Figure 17. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different levels of infant mortality on the mean muriqui population size at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

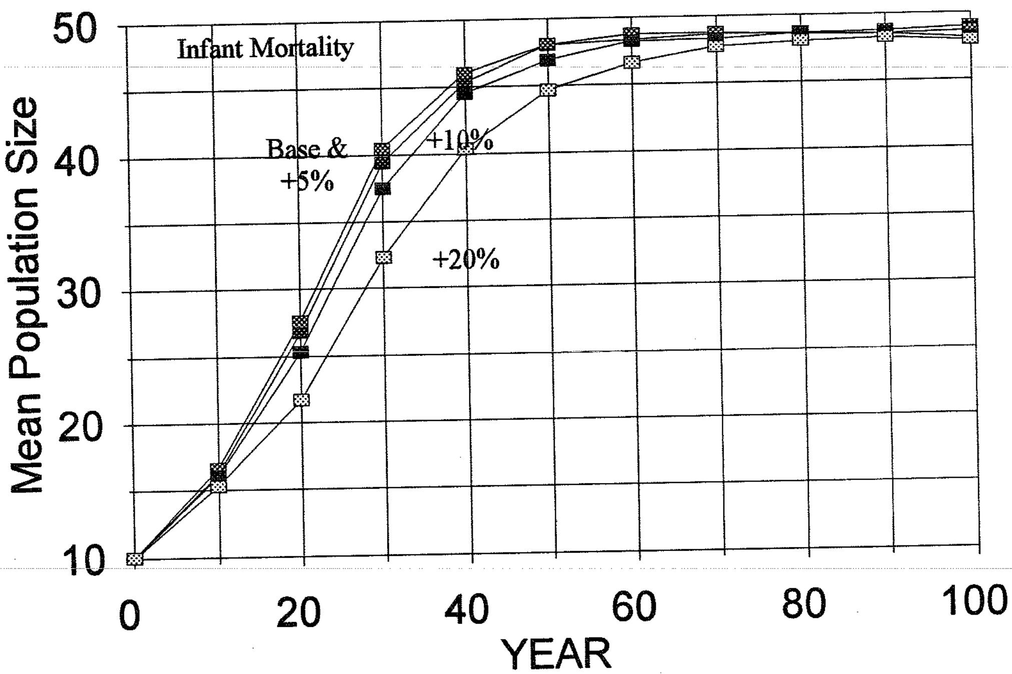


Figure 18. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different levels of infant mortality on the mean remaining heterozygosity in muriqui populations at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

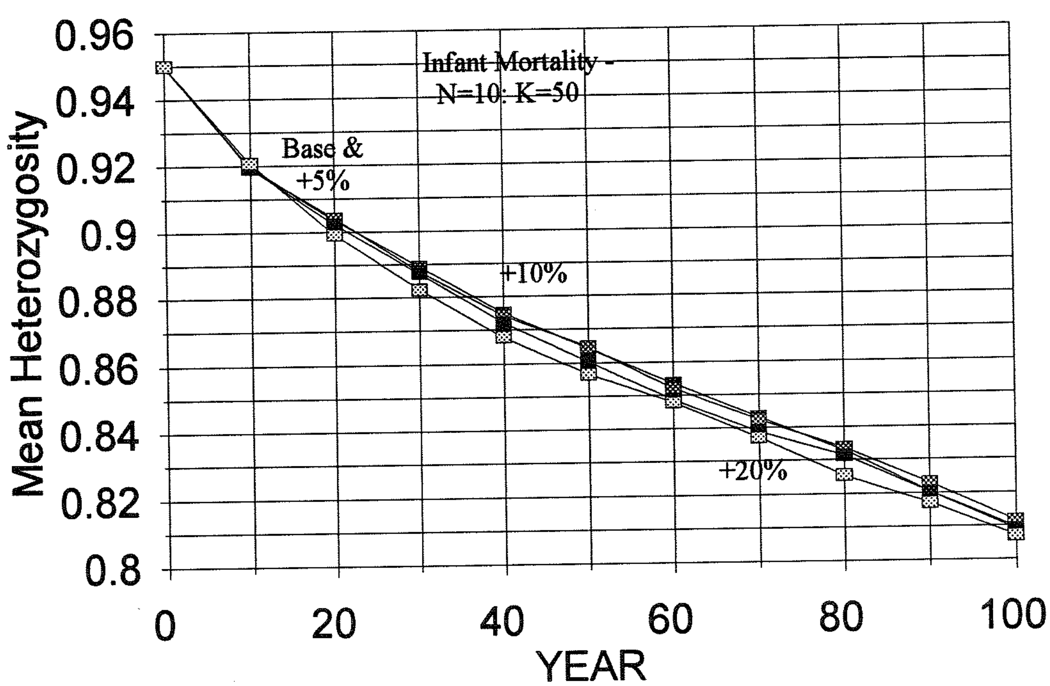


Figure 19. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different values for sex ratio at birth on the mean muriqui population size at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

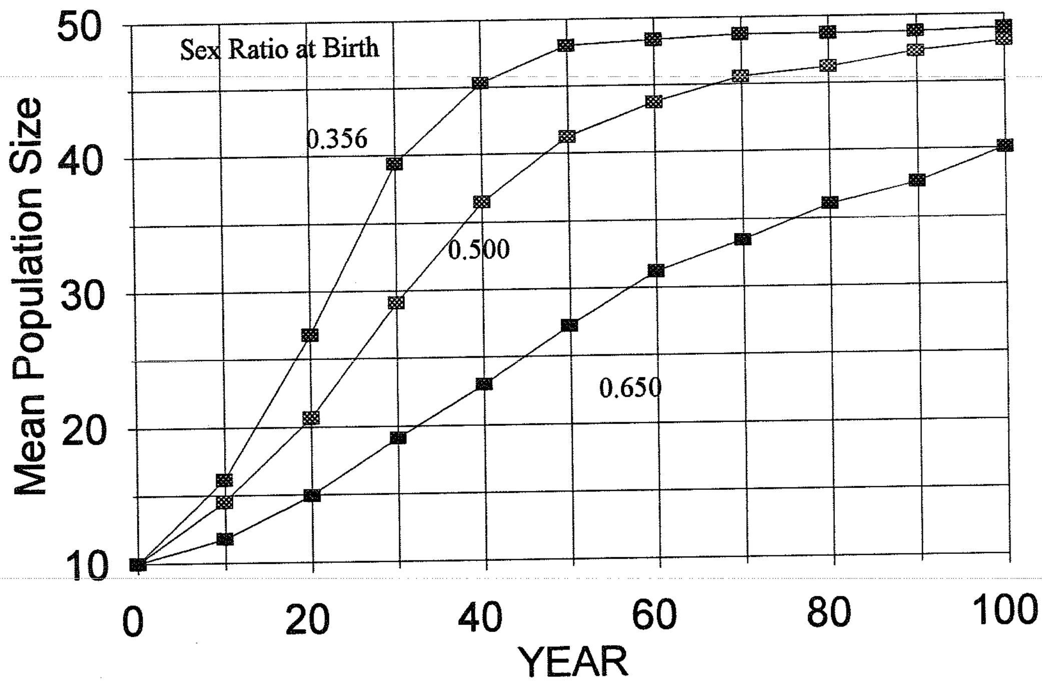


Figure 20. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different values for sex ratio at birth on the mean remaining heterozygosity in muriqui populations at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

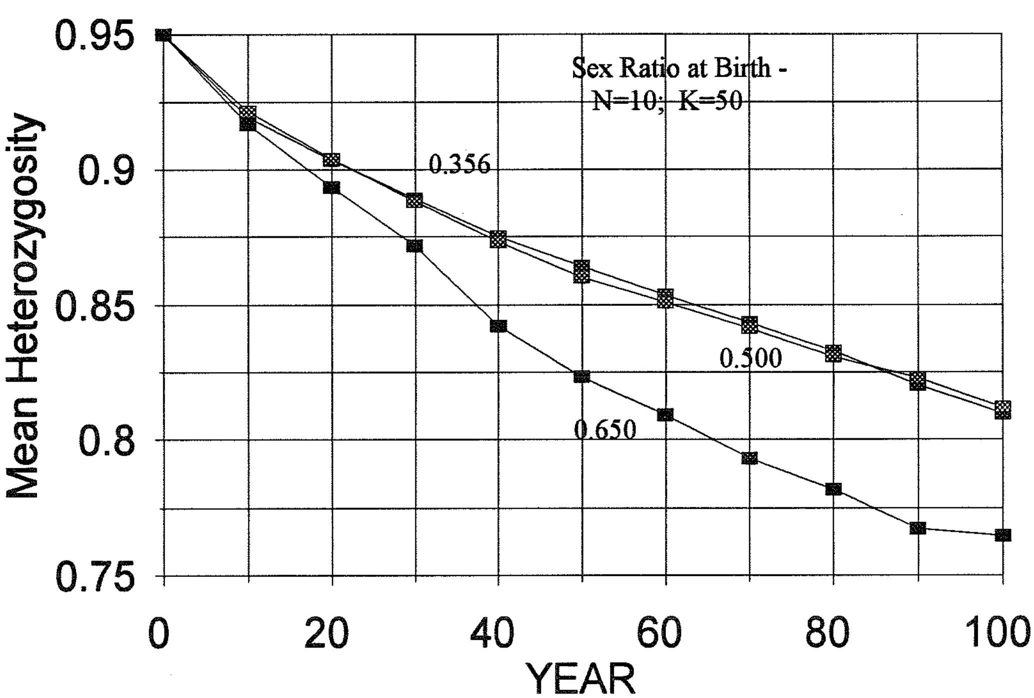


Figure 21. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different values for proportion of females breeding each year on the mean muriqui population size at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

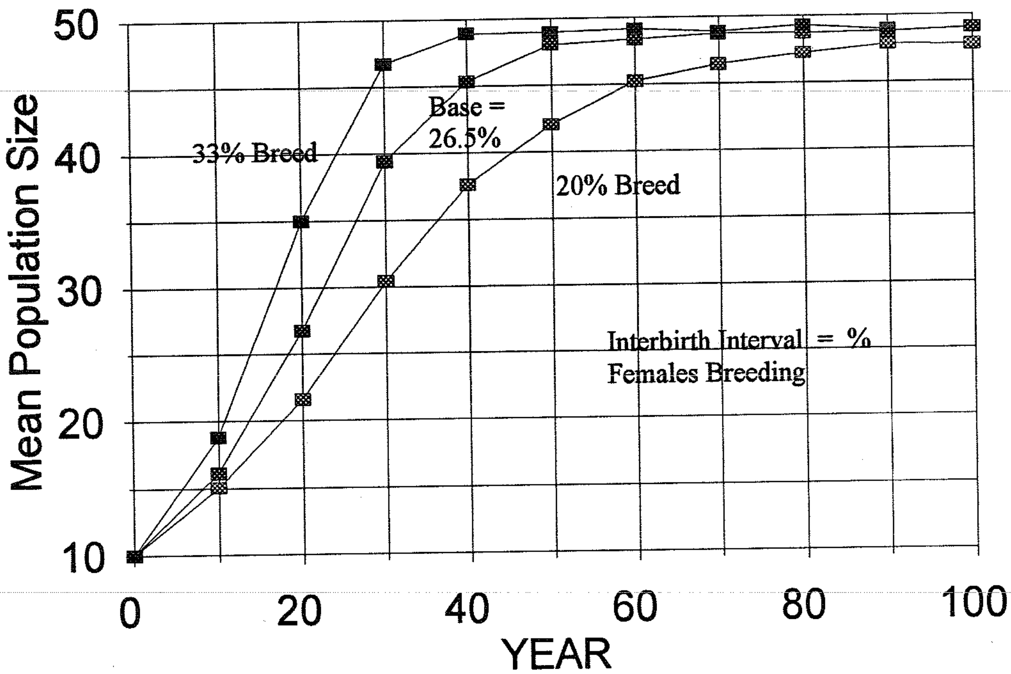


Figure 22. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with different values for proportion of females breeding each year on the mean remaining heterozygosity in muriqui populations at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

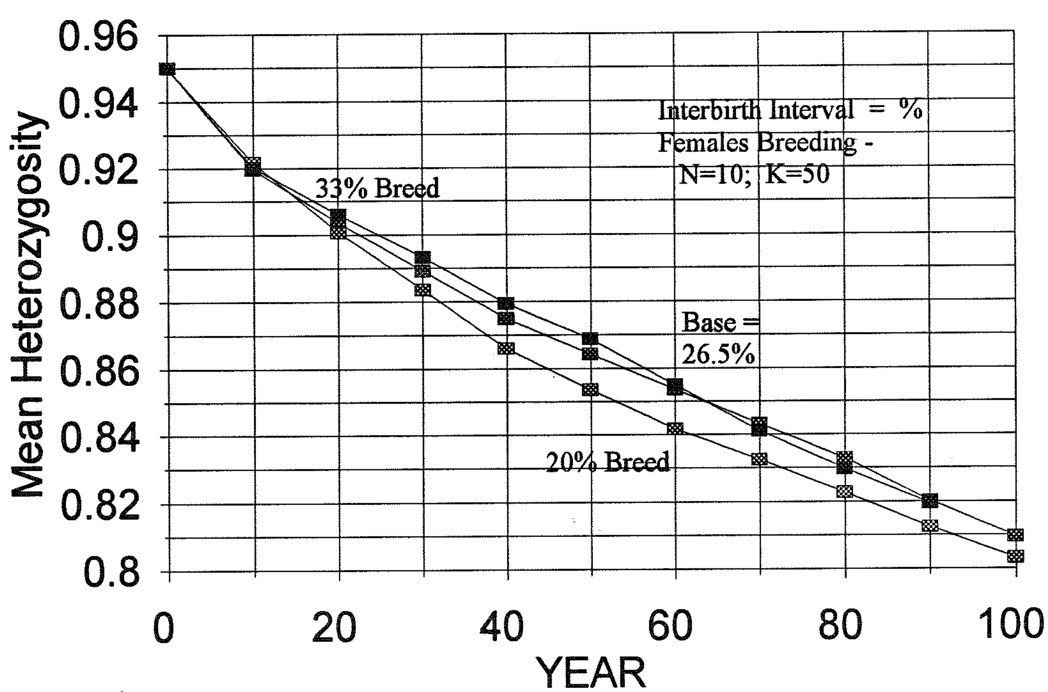


Figure 23. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with a 1% per year decline in carrying capacity for 50 years on the mean muriqui population size at 10 year intervals over 100 years. All other parameter values are as in the base scenario.

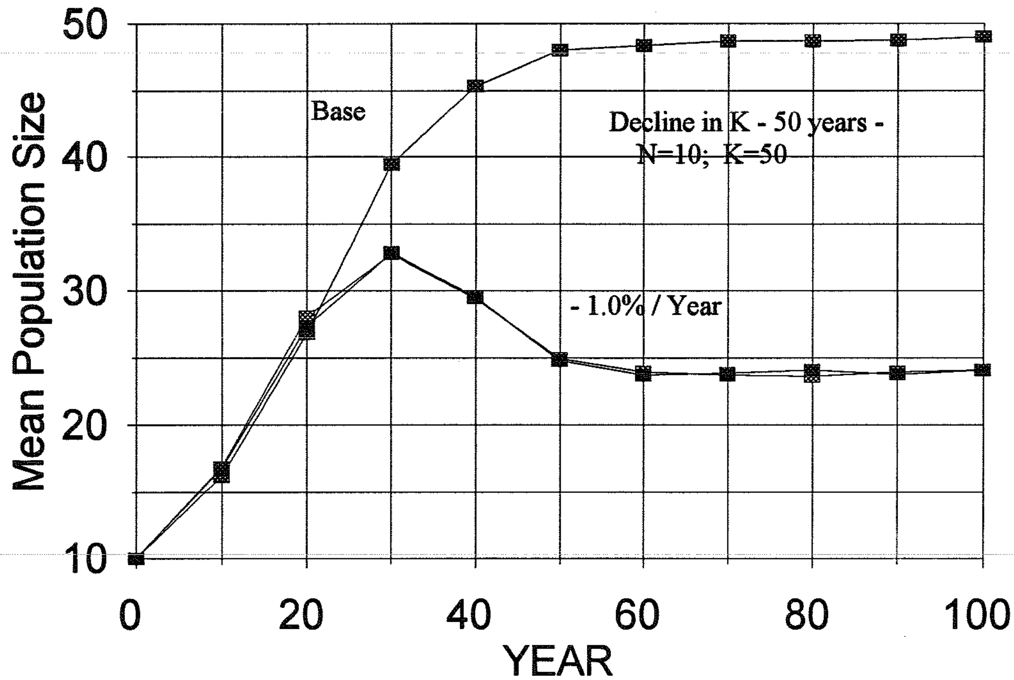
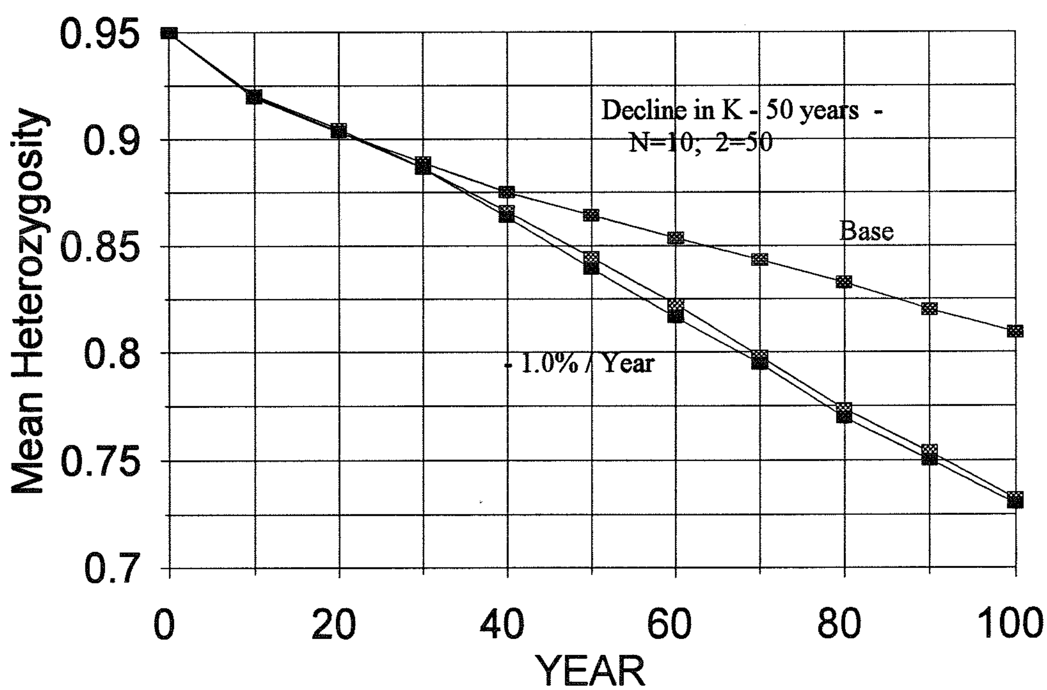


Figure 24. Effect of low starting population size (N = 10) and carrying capacity (K = 50) combined with a 1% decline in carrying capacity for 50 years mean remaining heterozygosity in muriqui populations at 10 year intervals over 100 years. All other parameter values are as in the base scenario.



Appendix I. Modeling Data Tables

Table 1. Simulation modeling of the effects and interactions of adult mortality, starting population size, carrying capacity and birth sex ratio on risk of risk extinction and population dynamics of the muriqui, *Brachyteles arachnoides.* The parameter values for the base scenario (file # QUI.002) were based upon the field work of K. Strier at Caratinga.

	Mort.	Pop	Cap		Results after 100 Years - Projections						
File #	F & M	N	K	det r	stoc r	SD(r)	PE	N	SD(N)	Het	T Ext
Birth Sex ratio = 0.356											
QUI.002	1 1.5	50	240	0.051	0.05	0.063	0.0	236.21	9.69	95.94	0.0
QUI.003	5 5.5			0.031	0.029	0.065	0.0	231.03	18.34	94.61	0.0
QUI.004	10 10			0.007	0.004	0.076	0.02	93.93	52.85	86.79	71.0
QUI.005	15 15			-0.017	-0.025	0.109	0.62	15.93	10.53	68.3	68.3
QUI.006	1 1.5		50	0.051	0.049	0.073	0.0	48.64	2.86	87.08	0.0
QUI.007	5 5.5			0.031	0.028	0.075	0.0	46.96	4.53	85.88	0.0
QUI.008	10 10			0.007	0.004	0.086	0.065	36.27	12.22	79.57	77.3
QUI.009	15 15			-0.017	-0.027	0.111	0.73	14.15	8.84	66.29	69.8
QUI.010	1 1.5	10	240	0.051	0.05	0.073	0.0	234.91	13.95	86.2	0.0
QUI.011	5 5.5			0.031	0.027	0.089	0.1	168.59	71.25	77.59	26.6
QUI.012	10 10			0.007	-0.005	0.123	0.715	29.23	19.72	60.6	37.7
QUI.013	15 15			-0.017	-0.033	0.148	1.0	0.0	0.0	0.0	27.7
QUI.014	1 1.5		50	0.051	0.047	0.079	0.005	49.01	2.51	80.95	14.0
QUI.015	5 5.5			0.031	0.028	0.09	0.07	46.02	6.46	75.28	25.3
QUI.016	10 10			0.007	-0.003	0.123	0.63	25.76	13.86	60.74	37.9
QUI.017	15 15			-0.017	-0.037	0.16	1.0	0.0	0.0	0.0	24.3
Birth Sex Ratio = 0.500											
QUI.018	1 1.5	50	240	0.037	0.037	0.058	0.0	234.02	11.8	96.25	0.0
QUI.019	5 5.5			0.016	0.015	0.064	0.0	186.97	62.01	93.6	0.0
QUI.020	10 10			-0.009	-0.013	0.094	0.225	28.3	20.29	79.64	77.9
QUI.021	15 15			-0.034	-0.043	0.125	0.935	7.0	3.83	52.82	60.9
QUI.022	1 1.5		50	0.037	0.035	0.068	0.0	48.37	3.24	89.15	0.0
QUI.023	5 5.5			0.016	0.013	0.075	0.0	42.39	9.06	86.97	0.0
QUI.024	10 10			-0.009	-0.014	0.097	0.23	18.53	11.98	73.7	77.3
QUI.025	15 15			-0.034	-0.042	0.124	0.885	7.09	4.66	58.46	58.0
QUI.026	1 1.5	10	240	0.037	0.035	0.074	0.0	212.47	44.39	85.36	0.0
QUI.027	5 5.5			0.016	0.011	0.101	0.24	64.22	49.2	72.02	46.0
QUI.028	10 10			-0.009	-0.017	0.138	0.825	11.34	7.41	54.81	42.8
QUI.029	15 15			-0.034	-0.044	0.16	1.0	0.0	0.0	0.0	26.8
QUI.030	1 1.5		50	0.037	0.034	0.079	0.005	48.07	4.49	81.18	24.0
QUI.031	5 5.5			0.016	0.011	0.103	0.21	34.53	13.77	70.38	44.5
QUI.032	10 10			-0.009	-0.02	0.143	0.865	14.26	10.98	56.63	41.3
QUI.033	15 15			-0.034	-0.043	0.162	1.0	0.0	0.0	0.0	27.2
Birth Sex Ratio = 0.650											
QUI.034	1 1.5	50	240	0.019	0.018	0.056	0.0	206.38	48.45	94.76	0.0
QUI.035	5 5.5			-0.003	-0.007	0.077	0.07	40.9	36.54	84.5	79.9
QUI.036	10 10			-0.03	-0.033	0.115	0.735	7.62	4.43	66.59	67.0
QUI.037	15 15			-0.057	-0.057	0.131	0.98	5.25	2.75	44.29	46.9
QUI.038	1 1.5		50	0.019	0.015	0.064	0.0	44.68	7.07	88.64	0.0
QUI.039	5 5.5			-0.003	-0.007	0.082	0.08	24.16	13.19	80.84	84.3
QUI.040	10 10			-0.03	-0.034	0.117	0.815	9.14	4.95	62.77	64.4
QUI.041	15 15			-0.057	-0.062	0.133	0.995	3.0	0.0	27.78	43.5
QUI.042	1 1.5	10	240	0.019	0.015	0.085	0.14	74.9	58.53	76.75	54.2
QUI.043	5 5.5			-0.003	-0.006	0.118	0.645	20.34	14.68	63.38	46.3
QUI.044	10 10			-0.03	-0.032	0.151	0.97	9.33	3.27	49.41	31.3
QUI.045	15 15			-0.057	-0.059	0.166	1.0	0.0	0.0	0.0	19.3
QUI.046	1 1.5		50	0.019	0.016	0.086	0.17	40.14	11.26	76.48	46.6
QUI.047	5 5.5			-0.003	-0.007	0.123	0.64	15.13	11.11	58.43	49.7
QUI.048	10 10			-0.03	-0.03	0.15	0.985	10.0	10.44	37.71	34.4
QUI.049	15 15			-0.057	-0.057	0.169	1.0	0.0	0.0	0.0	21.2

Table 2. Interaction of inbreeding depression with adult mortality, starting population size, carrying capacity and birth sex ratio on risk of risk extinction and population dynamics of the muriqui, *Brachyteles arachnoides.*

	Mort.	**Pop**	**Cap**		**Results after 100 Years - Projections**						
File #	**F & M**	**N**	**K**	**det r**	**stoc r**	**SD(r)**	**PE**	**N**	**SD(N)**	**Het**	**T Ext**
Inbreeding: LE = 3.14; Sex Ratio = 0.365											
QUI.A02	1 1.5	50	240	0.051	0.048	0.062	0.0	235.08	10.32	96.07	0.0
QUI.A03	5 5.5			0.031	0.027	0.064	0.0	228.38	19.98	94.81	0.0
QUI.A04	10 10			0.007	-0.002	0.079	0.06	61.57	45.38	85.02	79.7
QUI.A05	15 15			-0.017	-0.032	0.111	0.855	11.41	6.72	70.6	67.0
Inbreeding: LE = 3.14; Sex Ratio = 0.500											
QUI.A18	1 1.5	50	240	0.037	0.035	0.058	0.0	235.38	10.35	96.39	0.0
QUI.A19	5 5.5			0.016	0.012	0.064	0.0	168.11	64.93	93.37	0.0
QUI.A20	10 10			-0.009	-0.02	0.098	0.36	16.78	12.2	78.36	79.4
QUI.A21	15 15			-0.034	-0.046	0.123	0.97	8.0	5.02	71.54	58.0
Inbreeding: LE = 6.28; Sex Ratio = 0.365											
QUI.B02	1 1.5	50	240	0.051	0.047	0.061	0.0	234.97	11.27	96.13	0.0
QUI.B03	5 5.5			0.031	0.025	0.063	0.0	226.58	20.54	94.81	0.0
QUI.B04	10 10			0.007	-0.007	0.082	0.12	47.76	42.54	83.85	82.1
QUI.B05	15 15			-0.017	-0.036	0.111	0.93	7.71	4.68	67.75	66.0
Inbreeding: LE = 6.28; Sex Ratio = 0.500											
QUI.B18	1 1.5	50	240	0.037	0.033	0.058	0.0	234.39	11.02	96.34	0.0
QUI.B19	5 5.5			0.016	0.009	0.066	0.005	140.54	68.59	92.39	79.0
QUI.B20	10 10			-0.009	-0.024	0.101	0.47	13.06	12.04	74.63	79.5
QUI.B21	15 15			-0.034	-0.048	0.123	0.985	4.33	3.21	48.76	57.3

Table 3. Interaction of a 1% per year decline in habitat carrying capacity for 50 years with adult mortality, starting population size, carrying capacity and birth sex ratio on risk of risk extinction and population dynamics of the muriqui, *Brachyteles arachnoides*.

	Mort.	Pop	Cap		Results after 100 Years - Projections						
File #	F & M	N	K	det r	stoc r	SD(r)	PE	N	SD(N)	Het	T Ext
Birth Sex Ratio = 0.356											
K10.002	1 1.5	50	240	0.051	0.05	0.064	0.0	118.33	4.69	94.29	0.0
K10.003	5 5.5			0.031	0.03	0.067	0.0	115.99	7.25	92.93	0.0
K10.004	10 10			0.007	0.005	0.076	0.02	78.48	31.35	86.73	74.0
K10.005	15 15			-0.017	-0.025	0.107	0.615	18.16	11.61	69.45	68.5
K10.006	1 1.5		50	0.051	0.048	0.081	0.0	23.8	2.09	78.7	0.0
K10.007	5 5.5			0.031	0.028	0.086	0.02	22.65	3.02	76.14	71.0
K10.008	10 10			0.007	0.001	0.097	0.145	16.71	6.28	70.14	81.2
K10.009	15 15			-0.017	-0.026	0.112	0.795	9.22	5.65	57.86	68.2
K10.010	1 1.5	10	240	0.051	0.05	0.075	0.015	118.14	4.41	85.23	14.0
K10.011	5 5.5			0.031	0.026	0.091	0.095	100.39	27.59	75.22	39.1
K10.012	10 10			0.007	-0.002	0.122	0.685	35.29	24.02	62.36	38.0
K10.013	15 15			-0.017	-0.033	0.152	1.0	0.0	0.0	0.0	25.5
K10.014	1 1.5		50	0.051	0.048	0.086	0.02	24.08	2.13	73.24	30.8
K10.015	5 5.5			0.031	0.028	0.096	0.07	22.65	3.39	68.44	25.9
K10.016	10 10			0.007	-0.003	0.124	0.665	16.36	6.62	58.09	38.2
K10.017	15 15			-0.017	-0.034	0.154	1.0	0.0	0.0	0.0	26.1
Birth Sex Ratio = 0.500											
K10.018	1 1.5	50	240	0.037	0.037	0.061	0.0	116.87	7.18	94.85	0.0
K10.019	5 5.5			0.016	0.014	0.065	0.005	104.82	19.0	93.01	95.0
K10.020	10 10			-0.009	-0.014	0.095	0.235	24.83	18.16	78.82	75.6
K10.021	15 15			-0.034	-0.042	0.124	0.92	7.38	6.11	61.14	61.4
K10.022	1 1.5		50	0.037	0.034	0.077	0.0	23.33	2.8	81.46	0.0
K10.023	5 5.5			0.016	0.013	0.086	0.035	19.81	5.15	78.18	83.0
K10.024	10 10			-0.009	-0.017	0.108	0.365	11.17	6.11	66.46	75.0
K10.025	15 15			-0.034	-0.043	0.126	0.945	5.45	3.05	61.36	59.1
K10.026	1 1.5	10	240	0.037	0.035	0.075	0.005	113.42	16.41	84.43	51.0
K10.027	5 5.5			0.016	0.011	0.104	0.225	56.34	33.69	72.95	48.2
K10.028	10 10			-0.009	-0.019	0.139	0.85	14.7	9.83	55.37	41.0
K10.029	15 15			-0.034	-0.046	0.163	0.995	3.0	0.0	50.0	24.1
K10.030	1 1.5		50	0.037	0.033	0.085	0.0	22.98	3.01	77.43	0.0
K10.031	5 5.5			0.016	0.01	0.106	0.23	19.03	5.7	68.87	52.3
K10.032	10 10			-0.009	-0.017	0.137	0.85	11.47	6.11	56.62	41.0
K10.033	15 15			-0.034	-0.039	0.159	1.0	0.0	0.0	0.0	28.9
Birth Sex Ratio = 0.650											
K10.034	1 1.5	50	240	0.019	0.016	0.057	0.0	108.39	16.61	94.13	0.0
K10.035	5 5.5			-0.003	-0.006	0.076	0.06	38.91	26.89	84.48	84.3
K10.036	10 10			-0.03	-0.035	0.115	0.8	7.85	5.69	66.98	65.8
K10.037	15 15			-0.057	-0.06	0.129	0.99	4.5	2.12	46.53	45.0
K10.038	1 1.5		50	0.019	0.016	0.073	0.01	21.88	4.17	82.35	75.0
K10.039	5 5.5			-0.003	-0.007	0.091	0.165	14.43	6.42	74.55	74.2
K10.040	10 10			-0.03	-0.033	0.115	0.84	7.84	5.13	62.41	65.3
K10.041	15 15			-0.057	-0.06	0.133	1.0	0.0	0.0	0.0	45.5
K10.042	1 1.5	10	240	0.019	0.014	0.085	0.15	62.66	37.4	75.9	51.7
K10.043	5 5.5			-0.003	-0.006	0.12	0.615	16.78	14.66	61.08	50.1
K10.044	10 10			-0.03	-0.032	0.15	0.995	6.0	0.0	0.0	35.0
K10.045	15 15			-0.057	-0.056	0.167	1.0	0.0	0.0	0.0	21.5
K10.046	1 1.5		50	0.019	0.015	0.089	0.16	20.46	5.05	73.19	43.1
K10.047	5 5.5			-0.003	-0.007	0.122	0.61	12.12	6.74	61.35	45.9
K10.048	10 10			-0.03	-0.032	0.15	0.985	5.0	1.0	33.47	32.8
K10.049	15 15			-0.057	-0.059	0.168	1.0	0.0	0.0	0.0	19.8

Table 4. Effects of a decrease in proportion of females breeding each year to 20.0 % (5 year interbirth interval) interacting with adult mortality, starting population size, carrying capacity and birth sex ratio on risk of risk extinction and population dynamics of the muriqui, *Brachyteles arachnoides.*

	Mort.	Pop	Cap		Results after 100 Years - Projections						
File #	F & M	N	K	det r	stoc r	SD(r)	PE	N	SD(N)	Het	T Ext
Birth Sex Ratio = 0.356											
F20.002	1 1.5	50	240	0.036	0.034	0.065	0.0	233.13	11.71	95.75	0.0
F20.003	5 5.5			0.015	0.013	0.071	0.005	169.01	59.25	92.14	89.0
F20.004	10 10			-0.011	-0.015	0.097	0.305	24.63	18.95	73.19	73.7
F20.005	15 15			-0.036	-0.044	0.122	0.975	9.6	6.11	52.29	54.5
F20.006	1 1.5		50	0.036	0.034	0.074	0.0	47.76	3.45	87.64	0.0
F20.007	5 5.5			0.015	0.012	0.078	0.01	42.88	8.63	85.92	72.5
F20.008	10 10			-0.011	-0.015	0.101	0.36	18.03	10.71	70.53	73.8
F20.009	15 15			-0.036	-0.046	0.121	0.96	5.63	3.25	49.93	51.8
F20.010	1 1.5	10	240	0.036	0.034	0.079	0.02	208.61	47.55	83.4	49.0
F20.011	5 5.5			0.015	0.009	0.103	0.355	56.29	43.63	71.44	40.7
F20.012	10 10			-0.011	-0.022	0.137	0.935	11.23	6.18	57.92	33.5
F20.013	15 15			-0.036	-0.046	0.153	1.0	0.0	0.0	0.0	21.2
F20.014	1 1.5		50	0.036	0.034	0.081	0.015	47.79	3.7	80.33	18.7
F20.015	5 5.5			0.015	0.009	0.104	0.315	34.06	13.09	69.44	40.3
F20.016	10 10			-0.011	-0.021	0.137	0.93	10.43	11.51	45.25	34.3
F20.017	15 15			-0.036	-0.045	0.158	1.0	0.0	0.0	0.0	21.7
Birth Sex Ratio = 0.500											
F20.018	1 1.5	50	240	0.023	0.021	0.061	0.0	223.72	28.41	95.61	0.0
F20.019	5 5.5			0.001	-0.002	0.075	0.02	54.47	39.14	88.05	72.0
F20.020	10 10			-0.026	-0.033	0.114	0.745	7.65	5.21	65.17	68.3
F20.021	15 15			-0.052	-0.059	0.132	1.0	0.0	0.0	0.0	47.8
F20.022	1 1.5		50	0.023	0.021	0.07	0.0	46.34	4.8	89.95	0.0
F20.023	5 5.5			0.001	-0.003	0.083	0.075	29.5	13.23	83.99	81.1
F20.024	10 10			-0.026	-0.032	0.117	0.775	8.8	8.51	67.76	69.7
F20.025	15 15			-0.052	-0.061	0.134	1.0	0.0	0.0	0.0	44.8
F20.026	1 1.5	10	240	0.023	0.019	0.085	0.05	92.48	61.19	79.16	69.8
F20.027	5 5.5			0.001	-0.006	0.122	0.63	23.99	18.42	66.28	49.2
F20.028	10 10			-0.026	-0.032	0.149	0.99	5.5	2.12	55.13	34.8
F20.029	15 15			-0.052	-0.055	0.163	1.0	0.0	0.0	0.0	21.9
F20.030	1 1.5		50	0.023	0.018	0.088	0.085	40.44	12.31	76.8	44.5
F20.031	5 5.5			0.001	-0.006	0.121	0.605	19.42	14.23	64.22	47.7
F20.032	10 10			-0.026	-0.032	0.15	0.98	7.0	2.94	50.91	34.3
F20.033	15 15			-0.052	-0.055	0.163	1.0	0.0	0.0	0.0	21.5
Birth Sex Ratio = 0.650											
F20.034	1 1.5	50	240	0.005	0.003	0.062	0.005	87.3	56.01	91.35	81.0
F20.035	5 5.5			-0.018	-0.023	0.098	0.455	11.53	7.76	73.23	76.1
F20.036	10 10			-0.046	-0.049	0.123	0.985	3.0	1.73	33.33	55.0
F20.037	15 15			-0.074	-0.077	0.136	1.0	0.0	0.0	0.0	36.7
F20.038	1 1.5		50	0.005	0.001	0.069	0.05	34.63	12.54	87.19	79.0
F20.039	5 5.5			-0.018	-0.022	0.098	0.445	12.49	7.74	74.9	68.5
F20.040	10 10			-0.046	-0.047	0.125	0.97	4.33	1.97	58.46	55.3
F20.041	15 15			-0.074	-0.072	0.138	1.0	0.0	0.0	0.0	38.9
F20.042	1 1.5	10	240	0.005	0.002	0.096	0.33	25.21	24.53	70.81	49.6
F20.043	5 5.5			-0.018	-0.019	0.133	0.87	7.73	3.58	53.39	43.3
F20.044	10 10			-0.046	-0.046	0.154	0.99	6.5	0.71	55.43	25.3
F20.045	15 15			-0.074	-0.072	0.176	1.0	0.0	0.0	0.0	17.9
F20.046	1 1.5		50	0.005	0.001	0.101	0.44	23.47	13.41	69.23	55.4
F20.047	5 5.5			-0.018	-0.018	0.131	0.83	7.62	5.07	55.77	42.5
F20.048	10 10			-0.046	-0.044	0.154	1.0	0.0	0.0	0.0	26.3
F20.049	15 15			-0.074	-0.073	0.174	1.0	0.0	0.0	0.0	17.3

Table 5. Effects of an increase in proportion of females breeding each year to 33.0 % (3 year interbirth interval) interacting with adult mortality, starting population size, carrying capacity and birth sex ratio on the risk of extinction and population dynamics of the muriqui, *Brachyteles arachnoides.*

	Mort.	**Pop**	**Cap**		**Results after 100 Years - Projections**						
File #	**F & M**	**N**	**K**	**det r**	**stoc r**	**SD(r)**	**PE**	**N**	**SD(N)**	**Het**	**T Ext**
Birth Sex Ratio = 0.356											
F33.002	1 1.5	50	240	0.063	0.062	0.063	0.0	237.54	8.52	95.92	0.0
F33.003	5 5.5			0.044	0.044	0.063	0.0	235.63	10.84	95.07	0.0
F33.004	10 10			0.021	0.018	0.068	0.0	204.33	49.09	91.81	0.0
F33.005	15 15			-0.001	-0.006	0.088	0.145	46.36	34.64	79.13	77.4
F33.006	1 1.5		50	0.063	0.062	0.072	0.0	48.89	2.74	86.0	0.0
F33.007	5 5.5			0.044	0.041	0.075	0.0	48.52	2.85	85.07	0.0
F33.008	10 10			0.021	0.019	0.078	0.005	45.72	6.34	82.72	63.0
F33.009	15 15			-0.001	-0.006	0.093	0.225	28.65	12.65	75.53	78.7
F33.010	1 1.5	10	240	0.063	0.062	0.072	0.005	237.32	9.08	87.36	6.0
F33.011	5 5.5			0.044	0.041	0.082	0.04	221.66	41.18	81.23	11.9
F33.012	10 10			0.021	0.013	0.106	0.375	88.3	65.12	68.05	32.7
F33.013	15 15			-0.001	-0.019	0.142	0.93	19.57	12.46	54.85	30.8
F33.014	1 1.5		50	0.063	0.062	0.078	0.005	49.25	2.37	80.62	4.0
F33.015	5 5.5			0.044	0.041	0.086	0.025	47.83	4.36	76.54	23.6
F33.016	10 10			0.021	0.014	0.106	0.39	41.99	10.04	68.87	40.1
F33.017	15 15			-0.001	-0.02	0.138	0.945	19.64	14.25	51.68	31.1
Birth Sex Ratio = 0.500											
F33.018	1 1.5	50	240	0.049	0.048	0.059	0.0	236.78	9.08	96.36	0.0
F33.019	5 5.5			0.029	0.028	0.062	0.0	232.17	14.58	95.27	0.0
F33.020	10 10			0.004	0.001	0.076	0.035	81.07	54.9	87.05	72.3
F33.021	15 15			-0.019	-0.026	0.111	0.595	14.02	10.94	69.81	72.8
F33.022	1 1.5		50	0.049	0.047	0.069	0.0	48.79	2.7	88.34	0.0
F33.023	5 5.5			0.029	0.026	0.073	0.0	46.81	5.1	87.23	0.0
F33.024	10 10			0.004	0.0	0.086	0.035	31.89	13.25	80.86	82.9
F33.025	15 15			-0.019	-0.028	0.114	0.675	13.14	7.91	62.78	69.9
F33.026	1 1.5	10	240	0.049	0.047	0.071	0.005	234.7	19.93	87.25	53.0
F33.027	5 5.5			0.029	0.024	0.089	0.085	146.8	77.48	77.65	43.7
F33.028	10 10			0.004	-0.003	0.125	0.545	27.93	21.71	60.38	44.3
F33.029	15 15			-0.019	-0.03	0.151	0.965	9.0	5.8	42.75	33.1
F33.030	1 1.5		50	0.049	0.047	0.076	0.0	48.44	3.65	82.92	0.0
F33.031	5 5.5			0.029	0.025	0.09	0.04	44.17	9.8	76.32	41.6
F33.032	10 10			0.004	-0.004	0.125	0.595	25.4	13.94	61.33	43.4
F33.033	15 15			-0.019	-0.031	0.152	0.98	6.0	1.83	49.69	36.2
Birth Sex Ratio = 0.650											
F33.034	1 1.5	50	240	0.03	0.029	0.054	0.0	234.08	11.04	95.9	0.0
F33.035	5 5.5			0.009	0.006	0.067	0.015	111.57	64.59	90.32	63.3
F33.036	10 10			-0.017	-0.022	0.102	0.435	16.22	12.52	72.17	68.2
F33.037	15 15			-0.043	-0.046	0.129	0.965	8.29	5.94	58.69	56.0
F33.038	1 1.5		50	0.03	0.027	0.064	0.0	47.15	5.07	88.86	0.0
F33.039	5 5.5			0.009	0.004	0.074	0.02	36.86	12.33	85.23	83.0
F33.040	10 10			-0.017	-0.023	0.108	0.52	12.2	9.13	67.06	72.6
F33.041	15 15			-0.043	-0.048	0.128	0.97	5.33	2.66	46.56	54.0
F33.042	1 1.5	10	240	0.03	0.027	0.075	0.06	165.34	76.74	81.52	41.8
F33.043	5 5.5			0.009	0.005	0.108	0.385	42.63	37.11	68.24	46.8
F33.044	10 10			-0.017	-0.023	0.147	0.905	10.53	7.49	56.63	37.1
F33.045	15 15			-0.043	-0.047	0.165	1.0	0.0	0.0	0.0	24.1
F33.046	1 1.5		50	0.03	0.027	0.077	0.04	46.34	6.16	80.65	47.4
F33.047	5 5.5			0.009	0.006	0.105	0.345	30.31	14.42	71.3	53.3
F33.048	10 10			-0.017	-0.02	0.142	0.91	10.17	6.25	45.78	40.7
F33.049	15 15			-0.043	-0.045	0.167	1.0	0.0	0.0	0.0	26.6

Table 6. Effects of an increase in infant mortality to 5% interacting with adult mortality, starting population size, carrying capacity and birth sex ratio on risk of risk extinction and population dynamics of the muriqui, *Brachyteles arachnoides*.

	Mort.	**Pop**	**Cap**		**Results after 100 Years - Projections**						
File #	**F & M**	**N**	**K**	**det r**	**stoc r**	**SD(r)**	**PE**	**N**	**SD(N)**	**Het**	**T Ext**
Birth Sex Ratio = 0.356											
I05.002	1 1.5	50	240	0.049	0.048	0.062	0.0	235.97	9.13	96.0	0.0
I05.003	5 5.5			0.029	0.028	0.065	0.0	230.38	16.14	94.43	0.0
I05.004	10 10			0.005	0.002	0.079	0.025	80.17	52.2	85.9	66.4
I05.005	15 15			-0.019	-0.026	0.11	0.665	13.48	10.68	65.7	73.1
I05.006	1 1.5		50	0.049	0.047	0.072	0.0	48.83	2.7	87.1	0.0
I05.007	5 5.5			0.029	0.026	0.075	0.0	46.41	4.91	85.55	0.0
I05.008	10 10			0.005	0.003	0.085	0.04	33.99	12.15	80.35	86.0
I05.009	15 15			-0.019	-0.028	0.112	0.745	12.45	9.9	63.39	68.0
I05.010	1 1.5	10	240	0.049	0.048	0.074	0.01	236.37	11.16	85.6	12.5
I05.011	5 5.5			0.029	0.026	0.091	0.09	153.55	70.81	76.36	34.0
I05.012	10 10			0.005	-0.004	0.124	0.625	23.6	20.26	58.44	38.7
I05.013	15 15			-0.019	-0.038	0.155	1.0	0.0	0.0	0.0	25.7
I05.014	1 1.5		50	0.049	0.047	0.078	0.01	48.72	2.9	81.15	6.0
I05.015	5 5.5			0.029	0.025	0.093	0.095	44.65	8.58	73.96	29.0
I05.016	10 10			0.005	-0.005	0.124	0.715	24.98	15.8	62.7	37.1
I05.017	15 15			-0.019	-0.034	0.152	0.985	12.33	12.34	41.46	26.8
Birth Sex Ratio = 0.500											
I05.018	1 1.5	50	240	0.036	0.035	0.058	0.0	235.96	10.23	96.13	0.0
I05.019	5 5.5			0.015	0.014	0.064	0.0	180.73	60.18	93.64	0.0
I05.020	10 10			-0.011	-0.015	0.097	0.235	22.54	17.66	76.56	74.4
I05.021	15 15			-0.036	-0.043	0.124	0.935	5.54	3.6	58.36	59.3
I05.022	1 1.5		50	0.036	0.033	0.067	0.0	47.7	3.61	89.08	0.0
I05.023	5 5.5			0.015	0.012	0.074	0.005	43.0	8.07	87.44	96.0
I05.024	10 10			-0.011	-0.017	0.099	0.325	18.13	11.14	74.7	71.2
I05.025	15 15			-0.036	-0.042	0.124	0.95	7.4	5.78	58.59	60.5
I05.026	1 1.5	10	240	0.036	0.032	0.075	0.005	196.3	63.37	84.24	18.0
I05.027	5 5.5			0.015	0.007	0.104	0.3	53.29	46.65	71.88	43.1
I05.028	10 10			-0.011	-0.022	0.144	0.905	9.11	5.3	45.17	38.5
I05.029	15 15			-0.036	-0.047	0.161	1.0	0.0	0.0	0.0	25.3
I05.030	1 1.5		50	0.036	0.032	0.079	0.025	47.88	4.47	81.15	41.0
I05.031	5 5.5			0.015	0.009	0.103	0.215	33.74	13.86	69.26	47.6
I05.032	10 10			-0.011	-0.02	0.14	0.865	11.11	6.92	56.94	38.5
I05.033	15 15			-0.036	-0.043	0.163	1.0	0.0	0.0	0.0	26.7
Birth Sex Ratio = 0.650											
I05.034	1 1.5	50	240	0.017	0.016	0.055	0.0	197.07	54.39	94.61	0.0
I05.035	5 5.5			-0.005	-0.01	0.079	0.13	32.49	24.04	83.05	80.0
I05.036	10 10			-0.032	-0.036	0.115	0.85	7.3	4.57	63.16	65.4
I05.037	15 15			-0.058	-0.059	0.133	0.995	3.0	0.0	61.11	46.5
I05.038	1 1.5		50	0.017	0.014	0.064	0.01	43.91	8.58	89.09	71.5
I05.039	5 5.5			-0.005	-0.009	0.084	0.14	22.79	13.12	80.5	79.6
I05.040	10 10			-0.032	-0.034	0.119	0.78	7.95	5.43	63.15	63.8
I05.041	15 15			-0.058	-0.06	0.133	1.0	0.0	0.0	0.0	45.0
I05.042	1 1.5	10	240	0.017	0.013	0.085	0.17	69.43	55.95	75.33	50.7
I05.043	5 5.5			-0.005	-0.008	0.12	0.705	16.39	12.93	63.43	48.3
I05.044	10 10			-0.032	-0.032	0.151	0.98	14.25	14.06	39.05	31.7
I05.045	15 15			-0.058	-0.058	0.167	1.0	0.0	0.0	0.0	21.0
I05.046	1 1.5		50	0.017	0.015	0.085	0.13	38.94	12.74	75.15	47.5
I05.047	5 5.5			-0.005	-0.008	0.122	0.685	15.0	10.85	59.73	47.2
I05.048	10 10			-0.032	-0.032	0.149	0.985	4.33	2.52	39.63	32.0
I05.049	15 15			-0.058	-0.056	0.167	1.0	0.0	0.0	0.0	21.9

Table 7. Effects of an increase in annual infant mortality to 10% interacting with adult mortality, starting population size, carrying capacity and birth sex ratio on risk of risk extinction and population dynamics of the muriqui, *Brachyteles arachnoides*.

	Mort.	Pop	Cap		Results after 100 Years - Projections						
File #	**F & M**	**N**	**K**	**det r**	**stoc r**	**SD(r)**	**PE**	**N**	**SD(N)**	**Het**	**T Ext**
Birth Sex Ratio = 0.356											
I10.002	1 1.5	50	240	0.046	0.046	0.061	0.0	235.84	9.16	96.0	0.0
I10.003	5 5.5			0.026	0.025	0.064	0.0	226.78	22.14	94.45	0.0
I10.004	10 10			0.001	-0.001	0.079	0.06	66.54	41.61	84.94	73.1
I10.005	15 15			-0.022	-0.032	0.113	0.78	12.89	9.71	70.3	63.5
I10.006	1 1.5		50	0.046	0.045	0.071	0.0	48.51	2.93	87.57	0.0
I10.007	5 5.5			0.026	0.023	0.075	0.0	46.0	5.52	85.89	0.0
I10.008	10 10			0.001	-0.002	0.087	0.1	31.67	12.22	78.72	81.0
I10.009	15 15			-0.022	-0.032	0.116	0.835	10.88	6.7	67.74	66.7
I10.010	1 1.5	10	240	0.046	0.046	0.073	0.005	235.08	12.21	85.7	9.0
I10.011	5 5.5			0.026	0.023	0.09	0.165	139.56	70.26	76.6	27.5
I10.012	10 10			0.001	-0.01	0.127	0.78	22.45	20.41	60.06	37.8
I10.013	15 15			-0.022	-0.038	0.156	0.995	4.0	0.0	21.88	24.8
I10.014	1 1.5		50	0.046	0.045	0.078	0.005	48.19	3.73	80.89	2.0
I10.015	5 5.5			0.026	0.021	0.094	0.135	43.78	9.99	73.87	44.3
I10.016	10 10			0.001	-0.011	0.131	0.83	18.68	13.95	53.59	40.3
I10.017	15 15			-0.022	-0.039	0.156	1.0	0.0	0.0	0.0	25.2
Birth Sex Ratio = 0.500											
I10.018	1 1.5	50	240	0.033	0.032	0.056	0.0	234.64	14.59	96.19	0.0
I10.019	5 5.5			0.012	0.01	0.065	0.0	148.08	65.44	93.02	0.0
I10.020	10 10			-0.014	-0.02	0.101	0.39	16.76	10.73	73.63	78.3
I10.021	15 15			-0.039	-0.045	0.125	0.935	5.77	2.95	58.31	58.2
I10.022	1 1.5		50	0.033	0.031	0.066	0.0	48.34	3.34	89.37	0.0
I10.023	5 5.5			0.012	0.009	0.072	0.01	40.36	9.28	87.13	77.5
I10.024	10 10			-0.014	-0.018	0.102	0.33	15.82	9.73	70.47	78.0
I10.025	15 15			-0.039	-0.047	0.127	0.98	9.0	4.97	73.71	56.3
I10.026	1 1.5	10	240	0.033	0.031	0.076	0.02	186.67	63.44	83.81	37.8
I10.027	5 5.5			0.012	0.004	0.11	0.345	36.96	31.18	66.12	51.2
I10.028	10 10			-0.014	-0.024	0.148	0.89	8.59	5.59	50.24	36.1
I10.029	15 15			-0.039	-0.047	0.163	1.0	0.0	0.0	0.0	24.6
I10.030	1 1.5		50	0.033	0.03	0.079	0.015	47.46	5.39	81.23	22.0
I10.031	5 5.5			0.012	0.005	0.109	0.32	29.5	15.65	67.32	43.9
I10.032	10 10			-0.014	-0.022	0.142	0.9	10.8	6.57	43.88	36.8
I10.033	15 15			-0.039	-0.049	0.162	1.0	0.0	0.0	0.0	24.6
Birth Sex Raio = 0.650											
I10.034	1 1.5	50	240	0.015	0.013	0.055	0.0	171.9	59.9	94.21	0.0
I10.035	5 5.5			-0.008	-0.01	0.079	0.17	30.92	21.17	83.7	76.5
I10.036	10 10			-0.035	-0.037	0.118	0.875	7.6	3.84	58.59	64.7
I10.037	15 15			-0.062	-0.064	0.131	1.0	0.0	0.0	0.0	42.8
I10.038	1 1.5		50	0.015	0.011	0.065	0.005	42.75	9.62	88.55	87.0
I10.039	5 5.5			-0.008	-0.012	0.086	0.22	21.06	12.03	78.98	76.9
I10.040	10 10			-0.035	-0.038	0.121	0.865	7.19	4.52	60.61	63.8
I10.041	15 15			-0.062	-0.065	0.134	0.995	3.0	0.0	61.11	42.4
I10.042	1 1.5	10	240	0.015	0.011	0.089	0.18	53.73	43.29	72.88	47.5
I10.043	5 5.5			-0.008	-0.01	0.124	0.71	13.91	10.56	55.71	44.5
I10.044	10 10			-0.035	-0.035	0.151	0.99	7.5	6.36	32.64	29.9
I10.045	15 15			-0.062	-0.063	0.17	1.0	0.0	0.0	0.0	19.1
I10.046	1 1.5		50	0.015	0.011	0.088	0.165	32.95	14.5	72.86	51.3
I10.047	5 5.5			-0.008	-0.009	0.119	0.725	14.36	9.29	63.34	46.9
I10.048	10 10			-0.035	-0.036	0.153	0.985	3.67	2.08	35.19	30.5
I10.049	15 15			-0.062	-0.061	0.162	1.0	0.0	0.0	0.0	19.7

Table 8. Effects of an increase in annual infant mortality to 20% interacting with adult mortality, starting population size, carrying capacity and birth sex ratio on risk of risk extinction and population dynamics of the muriqui, *Brachyteles arachnoides.*

	Mort.	Pop	Cap		Results after 100 Years - Projections						
File #	**F & M**	**N**	**K**	**det r**	**stoc r**	**SD(r)**	**PE**	**N**	**SD(N)**	**Het**	**T Ext**
Birth Sex Ratio = 0.356											
I20.002	1 1.5	50	240	0.04	0.039	0.059	0.0	235.27	10.4	96.02	0.0
I20.003	5 5.5			0.019	0.017	0.064	0.0	196.36	51.72	93.26	0.0
I20.004	10 10			-0.006	-0.011	0.088	0.215	34.08	26.28	78.4	80.0
I20.005	15 15			-0.03	-0.038	0.117	0.9	7.6	6.7	57.44	58.6
I20.006	1 1.5		50	0.04	0.038	0.069	0.0	48.41	3.08	87.61	0.0
I20.007	5 5.5			0.019	0.018	0.072	0.0	45.73	5.38	86.2	0.0
I20.008	10 10			-0.006	-0.01	0.092	0.205	21.65	11.69	73.34	78.7
I20.009	15 15			-0.03	-0.039	0.116	0.935	12.0	9.78	60.93	59.1
I20.010	1 1.5	10	240	0.04	0.038	0.074	0.015	225.13	35.37	84.52	29.0
I20.011	5 5.5			0.019	0.014	0.096	0.23	77.33	53.1	72.8	41.0
I20.012	10 10			-0.006	-0.017	0.135	0.865	13.15	8.26	51.36	37.8
I20.013	15 15			-0.03	-0.042	0.156	1.0	0.0	0.0	0.0	23.0
I20.014	1 1.5		50	0.04	0.037	0.078	0.015	47.99	3.38	80.71	23.7
I20.015	5 5.5			0.019	0.015	0.095	0.245	39.76	11.35	72.29	39.9
I20.016	10 10			-0.006	-0.018	0.138	0.885	15.48	11.25	52.25	36.3
I20.017	15 15			-0.03	-0.043	0.156	1.0	0.0	0.0	0.0	23.6
Birth Sex Ratio = 0.500											
I20.018	1 1.5	50	240	0.027	0.026	0.056	0.0	231.8	16.26	95.84	0.0
I20.019	5 5.5			0.005	0.003	0.068	0.005	87.45	53.28	89.82	81.0
I20.020	10 10			-0.021	-0.027	0.108	0.59	10.51	7.34	66.95	71.4
I20.021	15 15			-0.047	-0.052	0.127	0.99	6.0	2.83	43.36	52.6
I20.022	1 1.5		50	0.027	0.025	0.065	0.0	47.47	3.95	89.55	0.0
I20.023	5 5.5			0.005	0.003	0.075	0.01	36.23	12.12	85.26	84.0
I20.024	10 10			-0.021	-0.027	0.109	0.59	11.33	8.52	68.13	73.5
I20.025	15 15			-0.047	-0.054	0.13	0.985	4.0	1.0	44.46	51.8
I20.026	1 1.5	10	240	0.027	0.023	0.079	0.05	131.06	73.16	81.08	43.9
I20.027	5 5.5			0.005	-0.002	0.115	0.485	23.48	16.28	64.85	49.4
I20.028	10 10			-0.021	-0.031	0.152	0.975	11.8	6.61	30.36	34.3
I20.029	15 15			-0.047	-0.055	0.159	1.0	0.0	0.0	0.0	21.6
I20.030	1 1.5		50	0.027	0.024	0.08	0.04	45.17	8.36	78.89	50.1
I20.031	5 5.5			0.005	-0.004	0.119	0.535	20.14	11.43	62.33	47.7
I20.032	10 10			-0.021	-0.029	0.149	0.97	5.17	1.17	49.63	35.4
I20.033	15 15			-0.047	-0.055	0.168	1.0	0.0	0.0	0.0	22.0
Birth Sex Ratio = 0.650											
I20.034	1 1.5	50	240	0.009	0.006	0.057	0.0	113.48	64.32	92.2	0.0
I20.035	5 5.5			-0.014	-0.017	0.089	0.29	19.13	13.63	77.35	72.6
I20.036	10 10			-0.042	-0.045	0.122	0.93	6.21	3.89	61.96	56.0
I20.037	15 15			-0.069	-0.07	0.133	1.0	0.0	0.0	0.0	40.4
I20.038	1 1.5		50	0.009	0.006	0.063	0.005	38.52	11.6	88.16	53.0
I20.039	5 5.5			-0.014	-0.018	0.093	0.325	15.12	9.92	75.66	70.0
I20.040	10 10			-0.042	-0.042	0.125	0.93	7.29	6.13	54.27	61.7
I20.041	15 15			-0.069	-0.072	0.139	1.0	0.0	0.0	0.0	39.2
I20.042	1 1.5	10	240	0.009	0.006	0.093	0.275	35.88	30.45	70.96	55.2
I20.043	5 5.5			-0.014	-0.014	0.126	0.825	10.0	5.55	55.41	44.4
I20.044	10 10			-0.042	-0.041	0.154	1.0	0.0	0.0	0.0	26.4
I20.045	15 15			-0.069	-0.069	0.173	1.0	0.0	0.0	0.0	18.6
I20.046	1 1.5		50	0.009	0.005	0.094	0.235	26.01	14.36	70.44	57.6
I20.047	5 5.5			-0.014	-0.016	0.13	0.835	9.15	7.18	54.5	47.6
I20.048	10 10			-0.042	-0.039	0.152	0.995	2.0	0.0	37.5	27.5
I20.049	15 15			-0.069	-0.065	0.162	1.0	0.0	0.0	0.0	18.5

Appendix II. Sample VORTEX input file

```
VORTEX 8.03 -- simulation of genetic and demographic stochasticity

MURIQUI.002
Mon May 25 15:12:53 1998

  1 population(s) simulated for 100 years, 200 iterations

  Extinction is defined as no animals of one or both sexes.

  No inbreeding depression

  First age of reproduction for females: 9   for males: 7
  Maximum breeding age (senescence): 35
  Sex ratio at birth (proportion males): 0.35600

Population 1:

  Polygynous mating; all adult males in the breeding pool.

   26.50 percent of adult females produce litters.
   EV in % adult females breeding = 12.40 SD

   Of those females producing litters, ...
   100.00 percent of females produce litters of size 1

   2.00 percent mortality of females between ages 0 and 1
    EV in % mortality = 1.000000 SD
   5.70 percent mortality of females between ages 1 and 2
    EV in % mortality = 2.800000 SD
   1.00 percent mortality of females between ages 2 and 3
    EV in % mortality = 1.000000 SD
   3.60 percent mortality of females between ages 3 and 4
    EV in % mortality = 1.800000 SD
   1.00 percent mortality of females between ages 4 and 5
    EV in % mortality = 1.000000 SD
   1.00 percent mortality of females between ages 5 and 6
    EV in % mortality = 1.000000 SD
   1.00 percent mortality of females between ages 6 and 7
    EV in % mortality = 1.000000 SD
   1.00 percent mortality of females between ages 7 and 8
    EV in % mortality = 1.000000 SD
   1.00 percent mortality of females between ages 8 and 9
    EV in % mortality = 1.000000 SD
   1.00 percent mortality of adult females (9<=age<=10)
    EV in % mortality = 1.000000 SD
   4.80 percent mortality of males between ages 0 and 1
    EV in % mortality = 2.400000 SD
   5.60 percent mortality of males between ages 1 and 2
    EV in % mortality = 2.800000 SD
   11.80 percent mortality of males between ages 2 and 3
    EV in % mortality = 5.900000 SD
   1.00 percent mortality of males between ages 3 and 4
    EV in % mortality = 1.000000 SD
   1.00 percent mortality of males between ages 4 and 5
    EV in % mortality = 1.000000 SD
   1.00 percent mortality of males between ages 5 and 6
    EV in % mortality = 1.000000 SD
```

1.00 percent mortality of males between ages 6 and 7
EV in % mortality = 1.000000 SD
1.52 percent mortality of adult males (7<=age<=8)
EV in % mortality = 1.500000 SD

EVs may be adjusted to closest values possible for binomial distribution.
EV in mortality will be concordant among age-sex classes
but independent from EV in reproduction.

Frequency of type 1 catastrophes: 6.670 percent
with 0.500 multiplicative effect on reproduction
and 0.900 multiplicative effect on survival

Frequency of type 2 catastrophes: 5.000 percent
with 0.000 multiplicative effect on reproduction
and 1.000 multiplicative effect on survival

Initial size of Population 1: 50
(set to reflect stable age distribution)

Age	1	2	3	4	5	6	7	8	9	10	11	12	13
Males	1	2	1	1	1	0	1	1	1	0	1	0	1
Females	3	2	2	2	2	2	1	2	1	1	2	1	1

Age	14	15	16	17	18	19	20	21	22	23	24	25	26
Males	0	1	0	1	0	0	1	0	0	0	1	0	0
Females	1	1	1	1	0	1	1	0	1	0	1	0	1

Age	27	28	29	30	31	32	33	34	35	Total
Males	0	0	1	0	0	0	0	0	0	16
Females	0	1	0	0	1	0	0	0	1	34

Carrying capacity = 240
EV in Carrying capacity = 0.00 SD

Deterministic population growth rate (based on females, with assumptions of no limitation of mates, no density dependence, and no inbreeding depression):

r = 0.051 lambda = 1.052 R0 = 2.711
Generation time for: females = 19.51 males = 17.80

Stable age distribution:

Age class	females	males
0	0.052	0.029
1	0.048	0.026
2	0.043	0.023
3	0.040	0.019
4	0.036	0.018
5	0.034	0.017
6	0.032	0.016
7	0.030	0.015
8	0.028	0.014
9	0.026	0.013
10	0.024	0.012
11	0.023	0.011
12	0.021	0.010
13	0.020	0.009
14	0.018	0.009
15	0.017	0.008
16	0.016	0.008
17	0.015	0.007
18	0.014	0.007
19	0.013	0.006

```
                     20        0.012      0.006
                     21        0.011      0.005
                     22        0.011      0.005
                     23        0.010      0.005
                     24        0.009      0.004
                     25        0.009      0.004
                     26        0.008      0.004
                     27        0.008      0.003
                     28        0.007      0.003
                     29        0.007      0.003
                     30        0.006      0.003
                     31        0.006      0.003
                     32        0.005      0.002
                     33        0.005      0.002
                     34        0.005      0.002
                     35        0.004      0.002

Ratio of adult (>= 7) males to adult (>= 9) females: 0.549

Population 1

Year 10
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =           82.17 (   1.04 SE,   14.68 SD)
     Expected heterozygosity =    0.984 (  0.000 SE,   0.002 SD)
     Observed heterozygosity =    0.999 (  0.000 SE,   0.002 SD)
     Number of extant alleles =   82.28 (   0.51 SE,    7.25 SD)

Year 20
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =          135.23 (   2.28 SE,   32.25 SD)
     Expected heterozygosity =    0.981 (  0.000 SE,   0.003 SD)
     Observed heterozygosity =    0.995 (  0.000 SE,   0.006 SD)
     Number of extant alleles =   75.84 (   0.56 SE,    7.99 SD)

Year 30
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =          208.44 (   2.54 SE,   35.91 SD)
     Expected heterozygosity =    0.978 (  0.000 SE,   0.003 SD)
     Observed heterozygosity =    0.989 (  0.001 SE,   0.007 SD)
     Number of extant alleles =   71.59 (   0.55 SE,    7.81 SD)

Year 40
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =          233.88 (   1.08 SE,   15.34 SD)
     Expected heterozygosity =    0.975 (  0.000 SE,   0.003 SD)
     Observed heterozygosity =    0.984 (  0.001 SE,   0.009 SD)
     Number of extant alleles =   66.37 (   0.47 SE,    6.65 SD)

Year 50
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =          237.34 (   0.59 SE,    8.31 SD)
     Expected heterozygosity =    0.972 (  0.000 SE,   0.004 SD)
     Observed heterozygosity =    0.979 (  0.001 SE,   0.010 SD)
     Number of extant alleles =   61.42 (   0.42 SE,    5.94 SD)
```

```
Year 60
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =           236.15 (   0.73 SE,   10.29 SD)
     Expected heterozygosity =    0.970 (  0.000 SE,   0.004 SD)
     Observed heterozygosity =    0.975 (  0.001 SE,   0.012 SD)
     Number of extant alleles =   57.08 (   0.40 SE,    5.64 SD)

Year 70
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =           236.81 (   0.60 SE,    8.55 SD)
     Expected heterozygosity =    0.967 (  0.000 SE,   0.005 SD)
     Observed heterozygosity =    0.972 (  0.001 SE,   0.011 SD)
     Number of extant alleles =   53.05 (   0.36 SE,    5.12 SD)

Year 80
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =           235.81 (   0.61 SE,    8.65 SD)
     Expected heterozygosity =    0.964 (  0.000 SE,   0.005 SD)
     Observed heterozygosity =    0.971 (  0.001 SE,   0.012 SD)
     Number of extant alleles =   49.69 (   0.34 SE,    4.76 SD)

Year 90
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =           237.22 (   0.59 SE,    8.28 SD)
     Expected heterozygosity =    0.962 (  0.000 SE,   0.006 SD)
     Observed heterozygosity =    0.970 (  0.001 SE,   0.013 SD)
     Number of extant alleles =   46.51 (   0.31 SE,    4.40 SD)

Year 100
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   200, P[S] = 1.000
     Population size =           236.21 (   0.69 SE,    9.69 SD)
     Expected heterozygosity =    0.959 (  0.000 SE,   0.007 SD)
     Observed heterozygosity =    0.966 (  0.001 SE,   0.013 SD)
     Number of extant alleles =   44.00 (   0.27 SE,    3.89 SD)

In 200 simulations of Population 1 for 100 years:
  0 went extinct and 200 survived.

This gives a probability of extinction of 0.0000 (0.0000 SE),
  or a probability of success of          1.0000 (0.0000 SE).

Mean final population for successful cases was 236.21 (0.69 SE, 9.69 SD)

   Age 1       2       3       4       5       6       7       8   Adults
Total
    6.54    6.19    4.67    4.59    4.27    3.98                   47.05
77.30  Males
   12.01   11.23    9.93    9.31    8.86    8.05    7.33    6.72   85.45
158.91  Females

Across all years, prior to carrying capacity truncation,
  mean growth rate (r) was 0.0499 (0.0004 SE, 0.0635 SD)
```

```
Final expected heterozygosity was      0.9594 ( 0.0005 SE,  0.0067 SD)
Final observed heterozygosity was      0.9660 ( 0.0009 SE,  0.0134 SD)
Final number of alleles was             44.00 (   0.27 SE,    3.89 SD)
*************************************************************************
```

Appendix III. Sample Vortex Output

```
MURIQUI.001     ***Output Filename***
Y     ***Graphing Files?***
N     ***Each Iteration?***
100     ***Simulations***
100     ***Years***
10     ***Reporting Interval***
0     ***Definition of Extinction***
1     ***Populations***
N     ***Inbreeding Depression?***
N     ***EV concordance between repro and surv?***
1     ***Types Of Catastrophes***
P     ***Monogamous, Polygynous, or Hermaphroditic***
9     ***Female Breeding Age***
7     ***Male Breeding Age***
35     ***Maximum Breeding Age***
0.356000     ***Sex Ratio***
1     ***Maximum Litter Size (0 = normal distribution) *****
N     ***Density Dependent Breeding?***
26.50  **breeding
8.00  **EV-breeding
0.000000  *FMort age 0
0.000000  ***EV
5.700000  *FMort age 1
1.400000  ***EV
0.000000  *FMort age 2
0.000000  ***EV
3.600000  *FMort age 3
1.000000  ***EV
0.000000  *FMort age 4
0.000000  ***EV
0.000000  *FMort age 5
0.000000  ***EV
0.000000  *FMort age 6
0.000000  ***EV
0.000000  *FMort age 7
0.000000  ***EV
0.000000  *FMort age 8
0.000000  ***EV
1.000000  *Adult FMort
0.200000  ***EV
4.800000  *MMort age 0
1.200000  ***EV
5.600000  *MMort age 1
1.400000  ***EV
11.800000  *MMort age 2
2.500000  ***EV
0.000000  *MMort age 3
0.000000  ***EV
0.000000  *MMort age 4
0.000000  ***EV
0.000000  *MMort age 5
0.000000  ***EV
0.000000  *MMort age 6
```

```
0.000000  ***EV
3.000000  *Adult MMort
1.000000  ***EV
6.670000     ***Probability Of Catastrophe 1***
0.500000     ***Severity--Reproduction***
0.900000     ***Severity--Survival***
Y     ***All Males Breeders?***
N     ***Start At Stable Age Distribution?***
2     ***Initial Females Age 1***
6     ***Initial Females Age 2***
1     ***Initial Females Age 3***
2     ***Initial Females Age 4***
1     ***Initial Females Age 5***
3     ***Initial Females Age 6***
0     ***Initial Females Age 7***
1     ***Initial Females Age 8***
0     ***Initial Females Age 9***
5     ***Initial Females Age 10***
0     ***Initial Females Age 11***
2     ***Initial Females Age 12***
0     ***Initial Females Age 13***
0     ***Initial Females Age 14***
1     ***Initial Females Age 15***
1     ***Initial Females Age 16***
0     ***Initial Females Age 17***
0     ***Initial Females Age 18***
8     ***Initial Females Age 19***
0     ***Initial Females Age 20***
0     ***Initial Females Age 21***
0     ***Initial Females Age 22***
0     ***Initial Females Age 23***
0     ***Initial Females Age 24***
0     ***Initial Females Age 25***
0     ***Initial Females Age 26***
0     ***Initial Females Age 27***
0     ***Initial Females Age 28***
0     ***Initial Females Age 29***
0     ***Initial Females Age 30***
0     ***Initial Females Age 31***
0     ***Initial Females Age 32***
0     ***Initial Females Age 33***
0     ***Initial Females Age 34***
0     ***Initial Females Age 35***
2     ***Initial Males Age 1***
2     ***Initial Males Age 2***
1     ***Initial Males Age 3***
0     ***Initial Males Age 4***
2     ***Initial Males Age 5***
1     ***Initial Males Age 6***
1     ***Initial Males Age 7***
2     ***Initial Males Age 8***
0     ***Initial Males Age 9***
0     ***Initial Males Age 10***
0     ***Initial Males Age 11***
2     ***Initial Males Age 12***
0     ***Initial Males Age 13***
0     ***Initial Males Age 14***
0     ***Initial Males Age 15***
0     ***Initial Males Age 16***
1     ***Initial Males Age 17***
```

```
0     ***Initial Males Age 18***
4     ***Initial Males Age 19***
0     ***Initial Males Age 20***
0     ***Initial Males Age 21***
0     ***Initial Males Age 22***
0     ***Initial Males Age 23***
0     ***Initial Males Age 24***
0     ***Initial Males Age 25***
0     ***Initial Males Age 26***
0     ***Initial Males Age 27***
0     ***Initial Males Age 28***
0     ***Initial Males Age 29***
0     ***Initial Males Age 30***
0     ***Initial Males Age 31***
0     ***Initial Males Age 32***
0     ***Initial Males Age 33***
0     ***Initial Males Age 34***
0     ***Initial Males Age 35***
240     ***K***
0.000000     ***EV--K***
N     ***Trend In K?***
N      ***Harvest?***
N     ***Supplement?***
N     ***AnotherSimulation?***
```

POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA)
FOR THE MURIQUI
(*Brachyteles arachnoides*)

Belo Horizonte, Brazil
23 - 26 May 1998

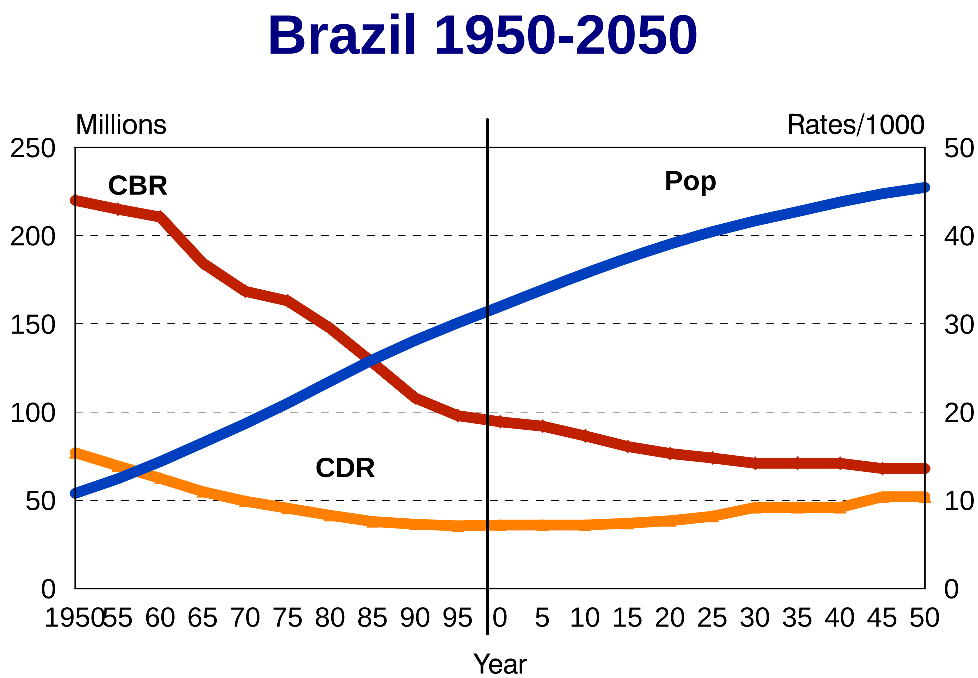
Report

Appendix I
Workshop Presentations

Appendix
Human Population Dynamics and
Conservation of the Muriqui
(G. Ness 24.5.98)

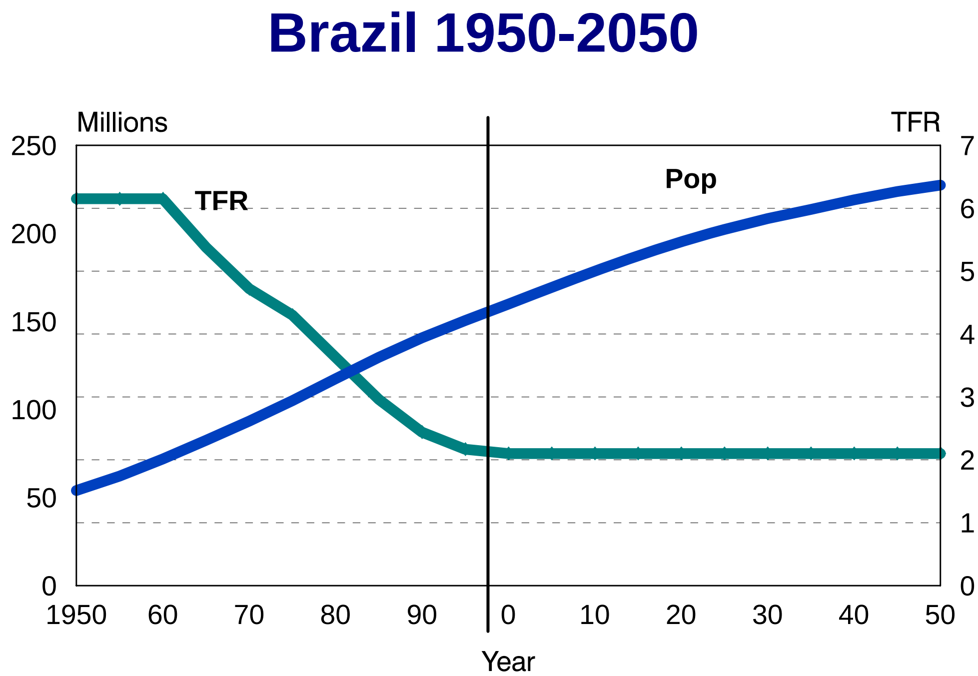
From our discussions in the workshop and the data that I can see, basic human demographic conditions do not seem to have a major impact on the Muriqui. Vital rates, population size, age-sex composition and distribution, seem far as the socio-economic issues of production. Brazil has completed its demographic transition. Death rates were already low by the 1950s; birth rates began to decline in the 1960s (Figure 1), and are now at replacement levels (Figure 2). Total population growth is now about 1.6 percent and declining. The current Brazilian population estimate is below the UN's low variant from the 1996 revision World Population Prospects. The proportion of young males (15-24) has also been declining since it reached its peak in 1980. Finally, the rural population has been in actual decline since the 1970s.

Figure 1



Participants in the workshop described the major human impact on the Muriqui to come from coffee and cattle production, hydroelectric development, road building and increasing traffic as major problems They also saw that in most rural areas people were moving out to the towns, returning seasonally to harvest coffee.

Figure 2



We also examined municipality level data available from the Brazilian government on CDRom, "SIEG." From this we produced two tables (Brazil1.xls and Brazil2.xls) showing a variety of possibly relevant population data for three Muriqui regions. These are for six municipalities around "Location 10," Caratinga, and the three municipalities adjacent to Carlos Bellow State Park. These are all somewhat more rural, usually slightly poorer (i.e. higher proportions with inadequate water and sanitary facilities), have slightly higher sex ratios, and are growing at rates both above and below those Brazil as a whole. None of these measures was, however, radically different from all Brazil. It was also noted that these data were inadequate for building a human population model with which to make projections. This was considered less important, however, since population projections do not seem to be necessary for VORTEX modeling. As the above report shows, it was more important to make estimates of habitat loss and monkey harvesting.

POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA)
FOR THE MURIQUI
(*Brachyteles arachnoides*)

Belo Horizonte, Brazil
23 - 26 May 1998

Report

Appendix II
Workshop Participants

WORKSHOP SOBRE O MURIQUI/MURIQUI WORKSHOP

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POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA) FOR THE MURIQUI (*Brachyteles arachnoides*)

Belo Horizonte, Brazil
23 - 26 May 1998

Report

Appendix III
Vortex Reference

Simulation Modeling and Population Viability Analysis

A model is any simplified representation of a real system. We use models in all aspects of our lives, in order to: (1) extract the important trends from complex processes, (2) permit comparison among systems, (3) facilitate analysis of causes of processes acting on the system, and (4) make predictions about the future. A complete description of a natural system, if it were possible, would often decrease our understanding relative to that provided by a good model, because there is "noise" in the system that is extraneous to the processes we wish to understand. For example, the typical representation of the growth of a wildlife population by an annual percent growth rate is a simplified mathematical model of the much more complex changes in population size. Representing population growth as an annual percent change assumes constant exponential growth, ignoring the irregular fluctuations as individuals are born or immigrate, and die or emigrate. For many purposes, such a simplified model of population growth is very useful, because it captures the essential information we might need regarding the average change in population size, and it allows us to make predictions about the future size of the population. A detailed description of the exact changes in numbers of individuals, while a true description of the population, would often be of much less value because the essential pattern would be obscured, and it would be difficult or impossible to make predictions about the future population size.

In considerations of the vulnerability of a population to extinction, as is so often required for conservation planning and management, the simple model of population growth as a constant annual rate of change is inadequate for our needs. The fluctuations in population size that are omitted from the standard ecological models of population change can cause population extinction, and therefore are often the primary focus of concern. In order to understand and predict the vulnerability of a wildlife population to extinction, we need to use a model which incorporates the processes which cause fluctuations in the population, as well as those which control the long-term trends in population size (Shaffer 1981). Many processes can cause fluctuations in population size: variation in the environment (such as weather, food supplies, and predation), genetic changes in the population (such as genetic drift, inbreeding, and response to natural selection), catastrophic effects (such as disease epidemics, floods, and droughts), decimation of the population or its habitats by humans, the chance results of the probabilistic events in the lives of individuals (sex determination, location of mates, breeding success, survival), and interactions among these factors (Gilpin and Soulé 1986).

Models of population dynamics which incorporate causes of fluctuations in population size in order to predict probabilities of extinction, and to help identify the processes which contribute to a population's vulnerability, are used in "Population Viability Analysis" (PVA) (Lacy 1993/4). For the purpose of predicting vulnerability to extinction, any and all population processes that impact population dynamics can be important. Much analysis of conservation issues is conducted by largely intuitive assessments by biologists with experience with the system. Assessments by experts can be quite valuable, and are often contrasted with "models" used to evaluate population vulnerability to extinction. Such a contrast is not valid, however, as *any* synthesis of facts and understanding of processes constitutes a model, even if it is a mental model within the mind of the expert and perhaps only vaguely specified to others (or even to the expert himself or herself).

A number of properties of the problem of assessing vulnerability of a population to extinction make it difficult to rely on mental or intuitive models. Numerous processes impact population dynamics, and many of the factors interact in complex ways. For example, increased fragmentation of habitat can make it more difficult to locate mates, can lead to greater mortality as individuals disperse greater distances across unsuitable habitat, and can lead to increased inbreeding which in turn can further reduce ability to attract mates and to survive. In addition, many of the processes impacting population dynamics are intrinsically probabilistic, with a random component. Sex determination, disease, predation, mate acquisition -- indeed, almost all events in the life of an individual -- are stochastic events, occurring with certain probabilities rather than with absolute certainty at any given time. The consequences of factors influencing population dynamics are often delayed for years or even generations. With a long-lived species, a population might persist for 20 to 40 years beyond the emergence of factors that ultimately cause extinction. Humans can synthesize mentally only a few factors at a time, most people have difficulty assessing probabilities intuitively, and it is difficult to consider delayed effects. Moreover, the data needed for models of population dynamics are often very uncertain. Optimal decision-making when data are uncertain is difficult, as it involves correct assessment of probabilities that the true values fall within certain ranges, adding yet another probabilistic or chance component to the evaluation of the situation.

The difficulty of incorporating multiple, interacting, probabilistic processes into a model that can utilize uncertain data has prevented (to date) development of analytical models (mathematical equations developed from theory) which encompass more than a small subset of the processes known to affect wildlife population dynamics. It is possible that the mental models of some biologists are sufficiently complex to predict accurately population vulnerabilities to extinction under a range of conditions, but it is not possible to assess objectively the precision of such intuitive assessments, and it is difficult to transfer that knowledge to others who need also to evaluate the situation. Computer simulation models have increasingly been used to assist in PVA. Although rarely as elegant as models framed in analytical equations, computer simulation models can be well suited for the complex task of evaluating risks of extinction. Simulation models can include as many factors that influence population dynamics as the modeler and the user of the model want to assess. Interactions between processes can be modeled, if the nature of those interactions can be specified. Probabilistic events can be easily simulated by computer programs, providing output that gives both the mean expected result and the range or distribution of possible outcomes. In theory, simulation programs can be used to build models of population dynamics that include all the knowledge of the system which is available to experts. In practice, the models will be simpler, because some factors are judged unlikely to be important, and because the persons who developed the model did not have access to the full array of expert knowledge.

Although computer simulation models can be complex and confusing, they are precisely defined and all the assumptions and algorithms can be examined. Therefore, the models are objective, testable, and open to challenge and improvement. PVA models allow use of all available data on the biology of the taxon, facilitate testing of the effects of unknown or uncertain data, and expedite the comparison of the likely results of various possible management options.

PVA models also have weaknesses and limitations. A model of the population dynamics does not define the goals for conservation planning. Goals, in terms of population growth, probability of persistence, number of extant populations, genetic diversity, or other measures of population performance must be defined by the management authorities before the results of population modeling can be used. Because the models incorporate many factors, the number of possibilities to test can seem endless, and it can be difficult to determine which of the factors that were analyzed are most important to the population dynamics. PVA models are necessarily incomplete. We can model only those factors which we understand and for which we can specify the parameters. Therefore, it is important to realize that the models probably underestimate the threats facing the population. Finally, the models are used to predict the long-term effects of the processes presently acting on the population. Many aspects of the situation could change radically within the time span that is modeled. Therefore, it is important to reassess the data and model results periodically, with changes made to the conservation programs as needed.

The VORTEX Population Viability Analysis Model

For the analyses presented here, the VORTEX computer software (Lacy 1993a) for population viability analysis was used. VORTEX models demographic stochasticity (the randomness of reproduction and deaths among individuals in a population), environmental variation in the annual birth and death rates, the impacts of sporadic catastrophes, and the effects of inbreeding in small populations. VORTEX also allows analysis of the effects of losses or gains in habitat, harvest or supplementation of populations, and movement of individuals among local populations.

Density dependence in mortality is modeled by specifying a carrying capacity of the habitat. When the population size exceeds the carrying capacity, additional morality is imposed across all age classes to bring the population back down to the carrying capacity. The carrying capacity can be specified to change linearly over time, to model losses or gains in the amount or quality of habitat. Density dependence in reproduction is modeled by specifying the proportion of adult females breeding each year as a function of the population size.

VORTEX models loss of genetic variation in populations, by simulating the transmission of alleles from parents to offspring at a hypothetical genetic locus. Each animal at the start of the simulation is assigned two unique alleles at the locus. During the simulation, VORTEX monitors how many of the original alleles remain within the population, and the average heterozygosity and gene diversity (or “expected heterozygosity”) relative to the starting levels. VORTEX also monitors the inbreeding coefficients of each animal, and can reduce the juvenile survival of inbred animals to model the effects of inbreeding depression.

VORTEX is an individual-based model. That is, VORTEX creates a representation of each animal in its memory and follows the fate of the animal through each year of its lifetime. VORTEX keeps track of the sex, age, and parentage of each animal. Demographic events (birth, sex determination, mating, dispersal, and death) are modeled by determining for each animal in each year of the simulation whether any of the events occur. (See figure below.) Events occur according to the specified age and sex-specific probabilities. Demographic stochasticity is therefore a consequence of the uncertainty regarding whether each demographic event occurs for any given animal.

VORTEX requires a lot of population-specific data. For example, the user must specify the amount of annual variation in each demographic rate caused by fluctuations in the environment. In addition, the frequency of each type of catastrophe (drought, flood, epidemic disease) and the effects of the catastrophes on survival and reproduction must be specified. Rates of migration (dispersal) between each pair of local populations must be specified. Because VORTEX requires specification of many biological parameters, it is not necessarily a good model for the examination of population dynamics that would result from some generalized life history. It is most usefully applied to the analysis of a specific population in a specific environment.

Further information on VORTEX is available in Lacy (1993a) and Lacy et al. (1995).

Dealing with Uncertainty

It is important to recognize that uncertainty regarding the biological parameters of a population and its consequent fate occurs at several levels and for independent reasons. Uncertainty can occur because the parameters have never been measured on the population. Uncertainty can occur because limited field data have yielded estimates with potentially large sampling error. Uncertainty can occur because independent studies have generated discordant estimates. Uncertainty can occur because environmental conditions or population status have been changing over time, and field surveys were conducted during periods which may not be representative of long-term averages. Uncertainty can occur because the environment will change in the future, so that measurements made in the past may not accurately predict future conditions.

Sensitivity testing is necessary to determine the extent to which uncertainty in input parameters results in uncertainty regarding the future fate of the pronghorn population. If alternative plausible parameter values result in divergent predictions for the population, then it is important to try to resolve the uncertainty with better data. Sensitivity of population dynamics to certain parameters also indicates that those parameters describe factors which could be critical determinants of population viability. Such factors are therefore good candidates for efficient management actions designed to ensure the persistence of the population.

The above kinds of uncertainty should be distinguished from several more sources of uncertainty about the future of the population. Even if long-term average demographic rates are known with precision, variation over time caused by fluctuating environmental conditions will cause uncertainty in the fate of the population at any given time in the future. Such environmental variation should be incorporated into the model used to assess population dynamics, and will generate a range of possible outcomes (perhaps represented as a mean and standard deviation) from the model. In addition, most biological processes are inherently stochastic, having a random component. The stochastic or probabilistic nature of survival, sex determination, transmission of genes, acquisition of mates, reproduction, and other processes preclude exact determination of the future state of a population. Such demographic stochasticity should also be incorporated into a population model, because such variability both increases our uncertainty about the future and can also change the expected or mean outcome relative to that which would result if there were no such variation. Finally, there is "uncertainty" which represents the alternative actions or interventions which might be pursued as a management strategy. The likely effectiveness of such management options can be explored by testing alternative scenarios in the model of population dynamics, in much the same way that sensitivity testing is used to explore the effects of uncertain biological parameters.

Results

Results reported for each scenario include:

Deterministic r -- The deterministic population growth rate, a projection of the mean rate of growth of the population expected from the average birth and death rates. Impacts of harvest, inbreeding, and density dependence are not considered in the calculation. When $r = 0$, a population with no growth is expected; $r < 0$ indicates population decline; $r > 0$ indicates long-term population growth. The value of r is approximately the rate of growth or decline per year.

The deterministic growth rate is the average population growth expected if the population is so large as to be unaffected by stochastic, random processes. The deterministic growth rate will correctly predict future population growth if: the population is presently at a stable age distribution; birth and death rates remain constant over time and space (i.e., not only do the probabilities remain constant, but the actual number of births and deaths each year match the expected values); there is no inbreeding depression; there is never a limitation of mates preventing some females from breeding; and there is no density dependence in birth or death rates, such as a Allee effects or a habitat "carrying capacity" limiting population growth. Because some or all of these assumptions are usually violated, the average population growth of real populations (and stochastically simulated ones) will usually be less than the deterministic growth rate.

Stochastic r -- The mean rate of stochastic population growth or decline demonstrated by the simulated populations, averaged across years and iterations, for all those simulated populations that are not extinct. This population growth rate is calculated each year of the simulation, prior to any truncation of the population size due to the population exceeding the carrying capacity. Usually, this stochastic r will be less than the deterministic r predicted from birth and death rates. The stochastic r from the simulations will be close to the deterministic r if the population growth is steady and robust. The stochastic r will be notably less than the deterministic r if the population is subjected to large fluctuations due to environmental variation, catastrophes, or the genetic and demographic instabilities inherent in small populations.

P(E) -- the probability of population extinction, determined by the proportion of, for example, 500 iterations within that given scenario that have gone extinct in the simulations. "Extinction" is defined in the VORTEX model as the lack of either sex.

N -- mean population size, averaged across those simulated populations which are not extinct.

SD(N) -- variation across simulated populations (expressed as the standard deviation) in the size of the population at each time interval. SDs greater than about half the size of mean N often indicate highly unstable population sizes, with some simulated populations very near extinction. When SD(N) is large relative to N, and especially when SD(N) increases over the years of the simulation, then the population is vulnerable to large random fluctuations and may go extinct even if the mean population growth rate is positive. SD(N) will be small and often declining relative to N when the population is either growing steadily toward the carrying capacity or declining rapidly (and deterministically) toward extinction. SD(N) will also decline considerably when the population size approaches and is limited by the carrying capacity.

H -- the gene diversity or expected heterozygosity of the extant populations, expressed as a percent of the initial gene diversity of the population. Fitness of individuals usually declines proportionately with gene diversity (Lacy 1993b), with a 10% decline in gene diversity typically causing about 15% decline in survival of captive mammals (Ralls et al. 1988). Impacts of inbreeding on wild populations are less well known, but may be more severe than those observed in captive populations (Jiménez et al. 1994). Adaptive response to natural selection is also expected to be proportional to gene diversity. Long-term conservation programs often set a goal of retaining 90% of initial gene diversity (Soulé et al. 1986). Reduction to 75% of gene diversity would be equivalent to one generation of full-sibling or parent-offspring inbreeding.

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