Preliminary Population Viability Analysis of the Critically Endangered Cat Ba Langur (*Trachypithecus poliocephalus*)

Caroline Lees, Benjamin M. Rawson, Alison M. Behie, Rebecca Hendershott and Neahga Leonard

2014

Preliminary Population Viability Analysis of the Critically Endangered Cat Ba Langur (*Trachypithecus poliocephalus*)

Caroline Lees, Benjamin Rawson, Alison Behie, Rebecca Hendershott and Neahga Leonard

Produced by: IUCN SSC Conservation Breeding Specialist Group

Citation: Lees, C., Rawson, B. M., Behie, A. M., Hendershott, R. and Leonard, N. (2014). *Preliminary Population Viability Analysis of the Critically Endangered Cat Ba Langur (Trachypithecus poliocephalus)*. IUCN SSC Conservation Breeding Specialist Group, Fauna & Flora International, Hanoi.

Cover Photo: Cat Ba langur group in Cua Dong area, Cat Ba Island, Vietnam. © Neahga Leonard.

Funded by: Critical Ecosystem Partnership Fund, Grant #64587 "*Development of a Holistic Approach to the Conservation of the Cat Ba langur*", to Fauna & Flora International – Vietnam Country Programme. The Critical Ecosystem Partnership Fund is a joint initiative of l'Agence Française de Développement, Conservation International, the European Union, the Global Environment Facility, the Government of Japan, the MacArthur Foundation, and the World Bank. A fundamental goal is to ensure civil society is engaged in biodiversity conservation. The work was also kindly supported by WildInvest.

Table of Contents

Acronyms v

Acknowledgements v

Introduction 1

The *VORTEX* Simulation Model 2

Modelled Populations 3

Management Scenarios Considered 3

Modelling Results 5

- **Retrospective Models** 5
- **Extinction Risk without Management Intervention** 7
  - Sanctuary 7
  - Cua Dong 7
  - Captive population 8
  - Meta-population 9
- **Potential Management Interventions** 9
  - Regular movements between sites 9
  - Translocation of females from Hang Cai 10
  - Add one male to the Hang Cai population 11
- **Intensive Management of the Captive Population** 13

Summary of Issues for Consideration 14

References 16

Appendix I: VORTEX Model Parameters 18

Tables

TABLE 1. POPULATION SIZE, SEX RATIO AND AGE STRUCTURE FOR REMAINING CAT BA LANGUR POPULATIONS. 3
TABLE 2. SUMMARY OF SCENARIOS MODELLED. 4
TABLE 3. EXTINCTION RISK (P) FOR POPULATIONS OF CAT BA LANGUR WITHOUT MANAGEMENT INTERVENTION. 7
TABLE 4. IMPACT ON EXTINCTION RISK AND INBREEDING COEFFICIENT RESULTING FROM THE TRANSLOCATION OF 5 FEMALES FROM HANG CAI. 10
TABLE 5. EXPECTED SHIFT IN EXTINCTION RISK FOR THE CAPTIVE POPULATION AFTER REMOVAL OF ONE 11-YEAR-OLD ADULT MALE. 12
TABLE 6. EXTINCTION RISK AND MEAN INBREEDING COEFFICIENTS FOR AN INTENSIVELY MANAGED *EX SITU* POPULATION. 14

Figures

FIGURE 1. RETROSPECTIVE MODELS FOR A POPULATION BEGINNING WITH 10 INDIVIDUALS. 5
FIGURE 2. RETROSPECTIVE MODELS FOR A POPULATION BEGINNING WITH 15 INDIVIDUALS. 5
FIGURE 3. RETROSPECTIVE MODELS FOR A POPULATION BEGINNING WITH 20 INDIVIDUALS. 6
FIGURE 4. RETROSPECTIVE MODELS FOR A META-POPULATION BEGINNING WITH TWO NON-INTERACTING SUB-UNITS OF N=15 AND N=13. 6
FIGURE 5. SANCTUARY PROJECTIONS WITHOUT MANAGEMENT INTERVENTION. 7
FIGURE 6. CUA DONG PROJECTIONS WITHOUT MANAGEMENT INTERVENTION. 8
FIGURE 7. CAPTIVE POPULATION PROJECTIONS WITHOUT MANAGEMENT INTERVENTION. 8
FIGURE 8. META-POPULATION PROJECTIONS WITHOUT MANAGEMENT INTERVENTION. 9
FIGURE 9. COMPARISON BETWEEN AN INTERCONNECTED META-POPULATION AND A SERIES OF ISOLATED SITES. 10
FIGURE 10. HANG CAI PROJECTIONS WITH ONE ADULT MALE ADDED AT YEAR 1. 11
FIGURE 11. IMPACT OF REMOVING ONE 11-YEAR-OLD ADULT MALE FROM THE CAPTIVE POPULATION. 12
FIGURE 12. IMPACT OF REMOVING ONE ADULT MALE FROM THE CUA DONG POPULATION. 13
FIGURE 13. IMPACT OF INTENSIFYING MANAGEMENT OF THE CAPTIVE POPULATION. 13

Acronyms

ANU	Australian National University
CBLCP	Cat Ba Langur Conservation Project
CBLTWG	Cat Ba Langur Technical Working Group
CBNP	Cat Ba National Park
CBSG	Conservation Breeding Specialist Group
CEPF	Critical Ecosystem Partnership Fund
EPRC	Endangered Primate Rescue Center
FFI	Fauna & Flora International
IUCN	International Union for Conservation of Nature
PSG	Primate Specialist Group
PVA	Population Viability Analysis
SSC	Species Survival Commission of the IUCN

Acknowledgements

The authors would like to thank Cat Ba National Park and Hai Phong and Cat Hai People's Committee for supporting population surveys for the Cat Ba langur, which form the basis of much of this work. Thanks to Luu Tuong Bach and Le Van Dung for conducting the preliminary population surveys in 2013. The CBLCP field staff and rangers of the Cat Ba National Park helped us refine the final numbers of langurs. Nguyen The Cuong kindly provided information about past numbers of langurs on the island. We also thank Carola Borries and Colin P. Groves for their independent reviews of the parameters for input into the PVA models. Thanks to Anthony Rylands for edits to this document.

Introduction

The Cat Ba Langur (*Trachypithecus poliocephalus*) has been consistently listed as one of the top 25 most endangered primates in the world. It is classified on the IUCN Red List of Threatened Species as Critically Endangered and in the Vietnam Red Data Book as Critically Endangered, and is one of 104 priority vertebrate species in the CEPF Ecosystem Profile for Indo-Burma. The species is endemic to Cat Ba Island, Vietnam. The total population is believed to have been 2400–2700 in the 1960s, declining to about 135 individuals by 1999 due to hunting. When the Cat Ba Langur Conservation Project (CBLCP) began the population was estimated at 40–60 individuals. Population surveys conducted in 2013 and subsequently updated with additional fieldwork show that the population is now reduced to just two breeding populations, remnant non-breeding groups, and lone individuals. One breeding population in the Sanctuary of Cat Ba National Park (CBNP) numbers about 31 individuals, while the second in Cua Dong and Viet Hai areas near Cat Ba town numbers 22. Another five females, isolated from breeding opportunities, are located in Gia Luan commune, while some unconfirmed records of lone individuals persist. The confirmed population count of the *in situ* population is 58 individuals, although supplementary surveys currently underway may change this final number slightly. Irrespective, it is one of the most endangered of all mammal species.

The CBLCP, in cooperation with CBNP, has been the lead implementing agency for the conservation of the Cat Ba Langur since 2000, recently partnering with Fauna & Flora International (FFI) and the Australian National University (ANU). Together, these partners are implementing a programme of protection, environmental education, monitoring and research to improve outcomes for the *in situ* population of the Cat Ba langur. Additionally, five Cat Ba langurs are held in the Endangered Primate Rescue Center (EPRC), managed and funded by Leipzig Zoo, in Cuc Phuong National Park. These animals comprise the entire global *ex situ* population.

There is an urgent and real need to develop a holistic conservation approach to ensure the continued survival of the Cat Ba langur. Part of this approach is to develop a Population Viability Analysis for the three remaining breeding populations (two *in situ* and one *ex situ*) to determine extinction risk under a business-as-usual scenario, i.e., without intervention. Various scenarios involving population management interventions can be tested against this baseline to determine their relative impacts on extinction risk.

The following report documents modelling work carried out using VORTEX (Lacy & Pollack, 2014), to help inform conservation planning decisions for Cat Ba Langurs (*Trachypithecus poliocephalus*), primarily for consideration by the Cat Ba Langur Technical Working Group (CBLTWG). The purpose of this report is to inform discussions rather than direct them. The modelling results are therefore illustrated and described, but interpretation is kept to a minimum and no conclusions are drawn. The report does not address the financial, technical, or political-logistical constraints of the translocation of animals.

Data for the models were compiled by a small working group: Ben Rawson (FFI, PSG), Alison Behie (ANU), Rebecca Hendershott (ANU) and Neahga Leonard (CBLCP). Information was drawn from recent and past surveys and observations of Cat Ba Langurs, published records of characteristics of similar species and, where these were lacking, the consensus view of this working group. Details of the parameters used in the model are provided in Appendix I. These parameters were externally reviewed by Prof. Colin Groves and Dr. Carola Borries to ensure their accuracy.

Given the uncertainty involved in establishing a reasonable representation of species' biology in this case, three baseline models were built to span a plausible range of life history profiles (details are provided in Appendix I). These are referred to throughout as:

- **Best Guess:** "best guess" performance with respect to juvenile mortality, breeding group size (i.e., number of females monopolised by a single male) and age at first breeding.
- **Optimistic:** same as the "best guess" model but with lower juvenile mortality.
- **Pessimistic:** higher juvenile mortality, greater monopolisation of females by individual males and increased age at first breeding.

It should be noted that though the models include a range of life-history types (from optimistic to pessimistic) and include the impact of year-to-year variations in reproductive success, mortality and sex ratio, they may all be optimistic with respect to several other factors as they assume:

- 100% protection from poaching and habitat encroachment.
- No density-related disadvantages (i.e., animals are able to locate each other and vital rates are not depressed in any way as populations reach estimated carrying capacity).
- All starting individuals for wild populations, plus the original founders of the captive population, are treated as unrelated (studbook data are used to seed the captive population but this only tracks known relationships).
- Only one kind of catastrophe will affect the population over the period considered (a single catastrophe is modelled, expected to occur once every 50 years and to result in 50% mortality).

The *VORTEX* Simulation Model

Computer modelling is a valuable and versatile tool for quantitatively assessing risk of decline and extinction of wildlife populations, both free ranging and managed. Complex and interacting factors that influence population persistence and health can be explored, including natural and anthropogenic causes. Models can also be used to evaluate the effects of alternative management strategies to identify the most effective conservation actions for a population or species and to identify research needs. Such an evaluation of population persistence under current and varying conditions is commonly referred to as a Population Viability Analysis (PVA).

The software used in these analyses is the simulation program VORTEX (v10.0) (Lacy & Pollack, 2014). VORTEX is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events, on small wild or captive populations. VORTEX models population dynamics as discrete, sequential events that occur according to defined probabilities. The program begins by either creating individuals to form the starting population, or by importing individuals from a studbook database. It then steps through life-cycle events (e.g., births, deaths, dispersal, catastrophic events), for each individual and, typically, on an annual basis. Events such as breeding success, litter size, sex at birth, and survival are determined based upon designated probabilities that incorporate both demographic stochasticity and annual environmental variation. Consequently, each run (iteration) of the model gives a different result. By running the model hundreds of times, it is possible to examine the probable outcome and range of possibilities. For a more detailed explanation of VORTEX and its use in population viability analysis, see Lacy (1993, 2000) and Miller and Lacy (2005).

Modelled Populations

Cat Ba Langurs exist at a number of sites. The sites are not naturally connected and each is modelled separately here in the site-specific scenarios. The two larger sites (Sanctuary and Cua Dong) contain a number of distinct groups. Though listed separately here for information (see Table 1), in the models animals move freely between these groups according to the rules set for breeding group dynamics. Table 1 below shows, for each site, the number of individuals and their sex and age-class when known. This was the best information available as of September 2014. Two infants have been observed recently which are not included in the starting populations of the models presented.

Table 1. Population size, sex ratio and age structure for remaining Cat Ba langur populations.

	CAT BA LANGUR GROUPS BY AREA												
	Sanctuary						Cua Dong				HC	CP	Total
	1	2*	3*	4**	5**	6	1	2	3	4	1	1	
Age/Sex Class													
Adult male	1	1	1	1	1	0	1	1	1	0	0	1	**9**
Adult female	5	4	2	1	1	0	5	2	0	1	5	1	**27**
Sub-adult male	0	0	0	0	0	1	0	1	2	0	0	1	**5**
Sub-adult female	4	0	0	0	0	0	0	1	0	0	0	0	**5**
Juvenile	5	1	0	0	0	0	4	2	0	0	0	1	**13**
Infant	1	1	0	0	0	0	1	0	0	0	0	1	**4**
Total	**16**	**7**	**3**	**2**	**2**	**1**	**11**	**7**	**3**	**1**	**5**	**5**	**63**

HC = Hang Cai group
CP = Cuc Phuong group held at EPRC
*Each contains one of the two females translocated in 2012
**These groups have not been seen for a few months

Age-classes applied in the models were characterised as follows:

- Infant - 0-1 year old
- Juvenile - 1-2 years old
- Sub-adult - 3-5 years old

In the models, animals are not assigned to age-classes but are given an age in years. Where no other information was available, the number of individuals listed in a single age-class was distributed evenly across the ages comprising that class. Where gender is not assigned (juveniles and infants) numbers were split 50:50 between males and females. For odd numbers the larger portion was assigned to males (as the more conservative estimate).

Management Scenarios Considered

Table 2 describes the management scenarios modelled. In summary, three types of scenario were modelled:

Retrospective scenarios: the purpose of these were to validate the models. Best Guess, Pessimistic and Optimistic models were run using 2003 starting parameters (to the extent that these are known) to establish whether or not they produced reasonable predictions of the 2014 population estimates.

Site-specific projections: Best Guess, Pessimistic and Optimistic models were run for each of the remaining populations (Sanctuary, Cua Dong and the Captive Population), to establish the likely futures for these populations in the absence of management intervention.

Management Scenarios: Site-specific models were manipulated to emulate a range of plausible management interventions, with the aim of comparing the relative value of these interventions in improving population viability.

Table 2. Summary of scenarios modelled.

Modelling Scenarios	Description/Rationale	Details
Retrospective analyses		
2003 – present	2003 starting population sizes of 10, 15 and 20 are considered. A 2003 population beginning with 2 groups (of 15 and 13 individuals) with no inter-group movements is also modelled.	No age structure or sex ratio data are available for 2003. Even sex ratios and stable age-structures are applied in all cases.
Site-specific scenarios		
Sanctuary	Future projections (next 100 years) for the **Sanctuary** population – Optimistic, Best Guess and Pessimistic scenarios shown.	Based on the age structure and sex-ratio described above, with carrying capacity = 280
Cua Dong	Future projections (next 100 years) for the **Cua Dong** population – Optimistic, Best Guess and Pessimistic scenarios shown.	Based on the age structure and sex-ratio described above, with carrying capacity = 100
Captive Population	Future projections (next 50 years) for the **Captive Population** (currently at EPRC) – Optimistic, Best Guess and Pessimistic scenarios shown.	Based on the age structure and sex ratio described above, includes studbook data describing relationship between individuals. Inbreeding impact reduced from 6.29 to 3.14 lethal equivalents; carrying capacity = 50.
Meta-population	**Meta-population** with no management – i.e., no movement between sub-populations and no genetic management in the captive population. Optimistic, Best Guess and Pessimistic scenarios shown.	Best guess and pessimistic scenarios, the unsexed captive infant is assigned as male. In Optimistic scenario female.
Management Interventions		
Meta-population	**Meta-population** with regular inter-site exchanges.	A best-case scenario for the meta-population but in reality would be difficult to engineer.
Dispersal of Hang Cai 5	Moving 5 females from **Hang Cai** (18+ years old) to the **Sanctuary**	Sanctuary plus 5 females aged 18 (n=2), 19 (n=2) and 20 (n=1).
	Moving 5 females from **Hang Cai** (18+ years old) to **Cua Dong**	Cua Dong plus 5 females aged 18 (n=2), 19 (n=2) and 20 (n=1).
	Moving 5 females from **Hang Cai** (18+ years old) to the **Captive Population** (currently at EPRC)	Captive population plus 5 females aged 18 (n=2), 19 (n=2) and 20 (n=1).
Addition of a male to Hang Cai	**Hang Cai** females plus one 8 year-old male.	Carrying capacity = 50.
	Captive Population 8 year-old male removed	
	Cua Dong Populations with one male removed	
Intensive management of captive population	**Captive Population** plus 5 **Hang Cai** females plus genetic management (preferential pairing of individuals of high genetic value)	Captive population plus 5 females aged 18 (n=2), 19 (n=2) and 20 (n=1). Genetic management by mean kinship enabled.

Modelling Results

Retrospective Models

Some unpublished data from the CBLCP are available on approximate population sizes from 2003. Data suggest with fairly high certainty that 10–11 animals persisted in Cua Dong, or approximately 15 animals if Cua Dong and Viet Hai areas are considered as contiguous. Sanctuary numbers are less clear, but may have been as low as 13 individuals.

Optimistic, Best Guess and Pessimistic models for 2003 starting population sizes of n=10, 15 and 20, are shown in Figures 1, 2 and 3 to illustrate potential population growth since that time to the present day. Figure 4 shows results for a starting population comprising two non-interacting groups – one of 13 animals (the low estimate for the Sanctuary) and one of 15 animals (Cua Dong and Viet Hai aggregated populations assuming connectivity between them); aggregate population size only is shown in the graph. All graphs show mean population size each year, across 1000 iterations. Note that no 2003 data were available for age structure and sex ratio, factors which would be expected to affect growth. In the absence of better information, a 50:50 sex ratio with stable-age structure was used as a starting point.

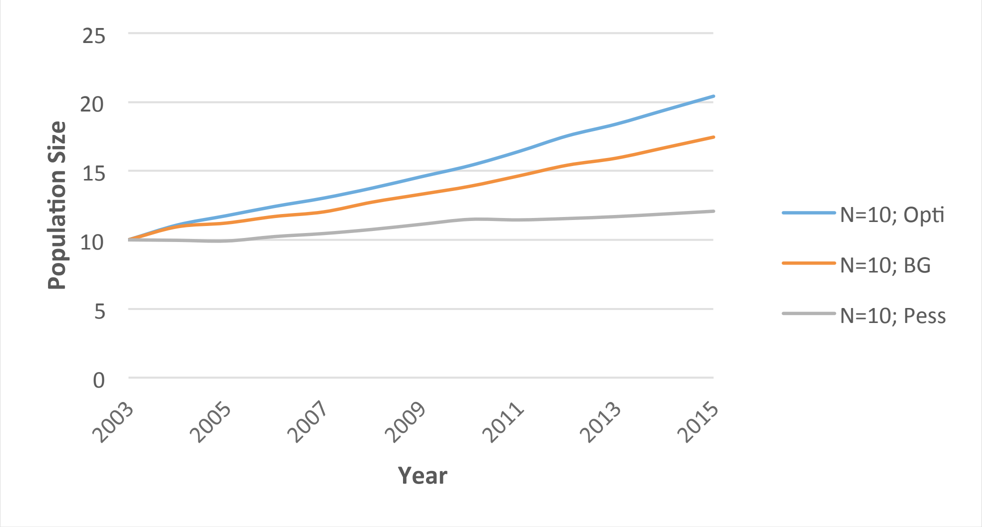

Figure 1. Retrospective models for a population beginning with 10 individuals.

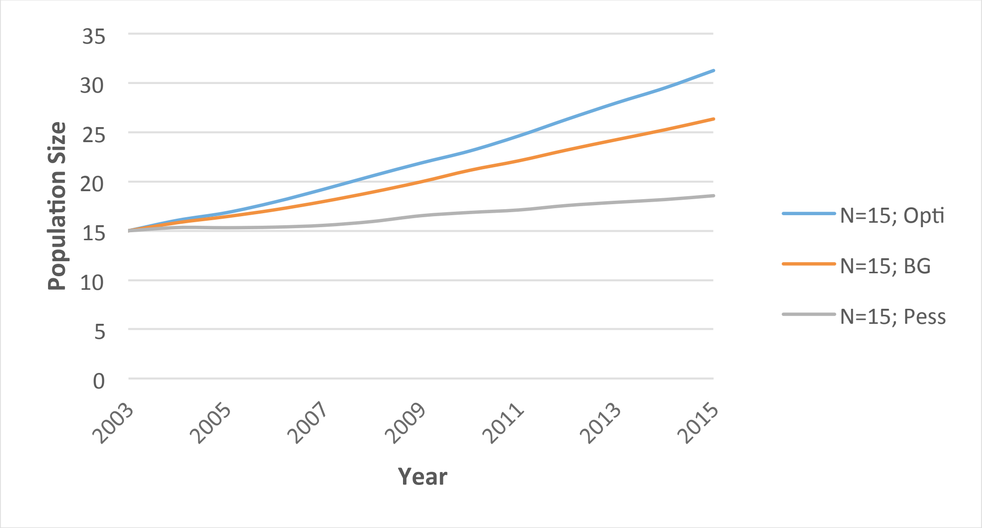

Figure 2. Retrospective models for a population beginning with 15 individuals.

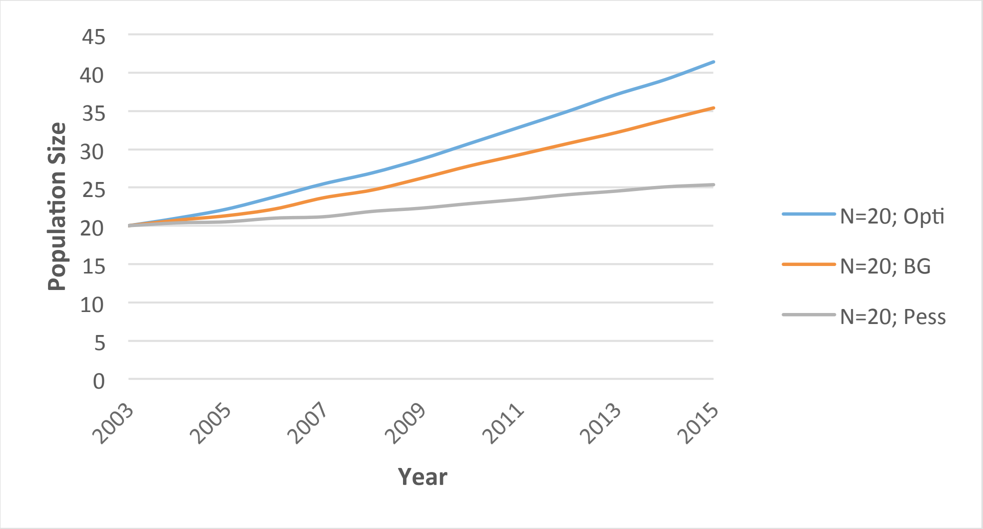

Figure 3. Retrospective models for a population beginning with 20 individuals.

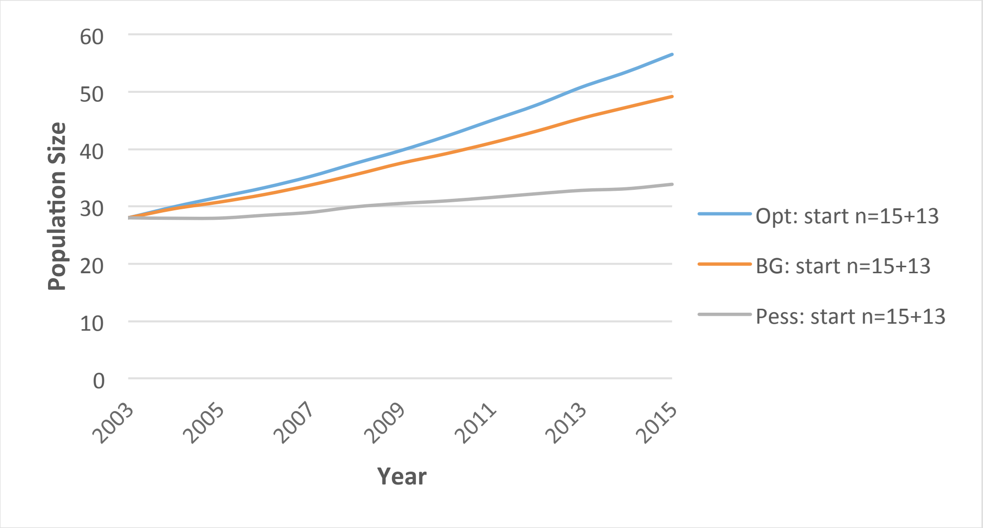

Figure 4. Retrospective models for a meta-population beginning with two non-interacting sub-units of n=15 and n=13.

A 2003 starting point of 10 individuals, using the Best Guess model, fairly accurately predicts the current population in Cua Dong (assuming no connectivity with Viet Hai) at 17 animals; the current population is actually 18 individuals. An aggregated 2003 population consisting of 28 individuals comprising a connected Cua Dong and Viet Hai population (15 individuals) and an unconnected Sanctuary population (13 individuals), fairly accurately predicts the current size of the aggregated breeding populations at 50 animals; the current actual population is 52 individuals.

In general, 2003 starting points provide average trajectories that are consistent with recorded observations. However, the variability across simulations was high in all cases, such that the current estimate of 52 individuals would not be wholly inconsistent with any of the retrospective models. Validating these models should be considered an ongoing project but this should not hold up their use in evaluating the relative impact of potential management interventions on population performance.

Extinction Risk without Management Intervention

The following table and figures illustrate the outputs of long-range models for each of the site-based populations under current conditions (i.e., with no additional management intervention). These "business as usual" figures act as a baseline against which management interventions can be compared for impact in reducing extinction risk. Site-based carrying capacities are assigned as follows: Sanctuary K=280; Cua Dong K=100; Captive Population K=50. A summary of extinction risk for each population without management intervention is provided in Table 3 below and includes Pessimistic, Best Guess and Optimistic projections.

Table 3. Extinction risk (P) for populations of Cat Ba langur without management intervention.

Site	Optimistic	Best Guess	Pessimistic
Sanctuary	0.3%	1.6%	10.6%
Cua Dong	2.4%	8.6%	40.5%
Captive	95%	98%	100%
Meta-population	0%	0%	10.7%

Extinction Risk (P) calculated at 100 years for wild populations and at 50 years for the captive population

Sanctuary

In the absence of management interventions in the Sanctuary, extinction risk appears relatively low in the Optimistic and Best Guess models with, on average, reasonable growth and less than 2% probability of extinction. The Pessimistic model, however, shows considerably poorer growth and a greater than 10% chance of extinction over a 100-year period (see Table 3 and Figure 5).

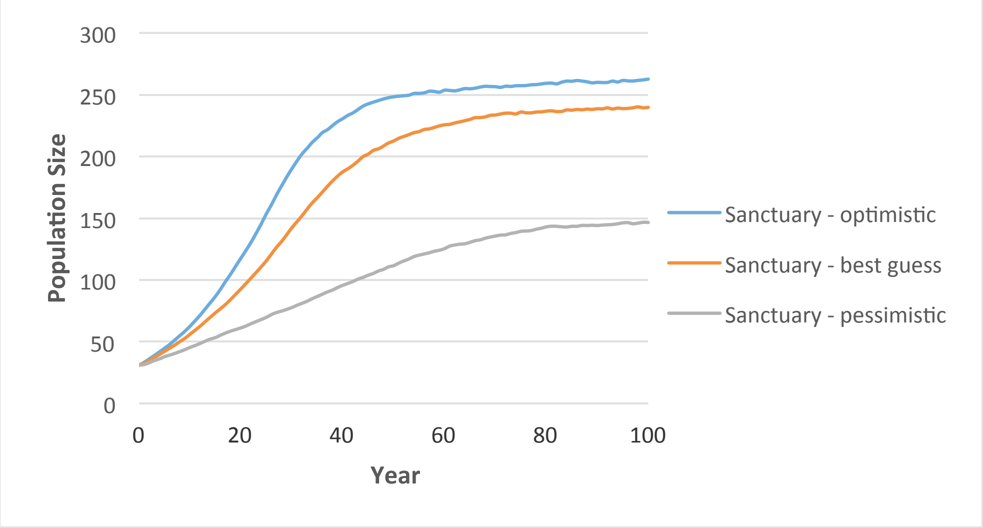

Figure 5. Sanctuary projections without management intervention.

Cua Dong

In the absence of management intervention the Cua Dong population models are similar to those for Sanctuary. However, the reduced population starting size and assumed smaller carrying capacity of the site slows growth and increases risk of extinction across all three scenarios. Extinction risk is

2.4%, 8.6% and 40.5% in Optimistic, Best Guess and Pessimistic scenarios respectively (see Table 3 and Figure 6).

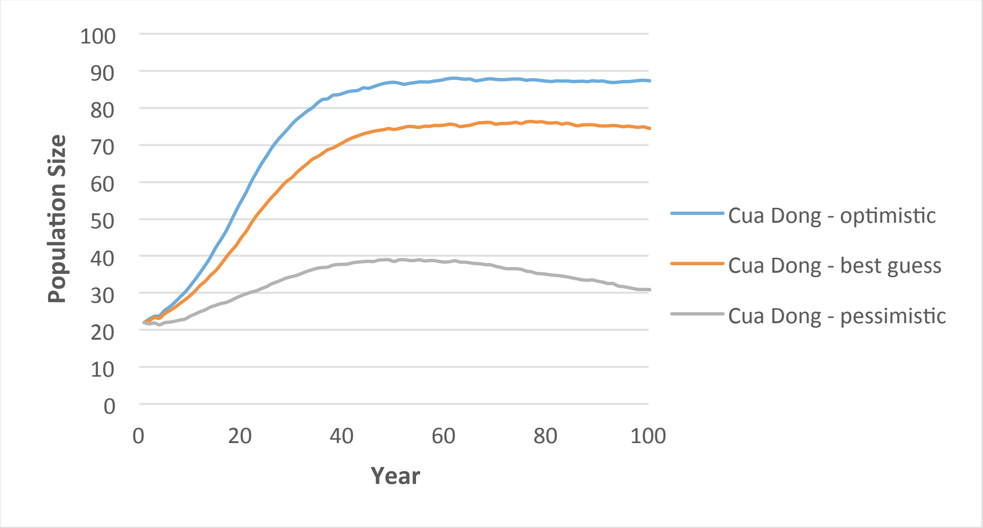

Figure 6. Cua Dong projections without management intervention.

Captive population

Currently the only captive population of the Cat Ba langur is at the Endangered Primate Rescue Center (EPRC) in Cuc Phuong National Park. Pessimistic, Best Guess and Optimistic trajectories for the captive population in the absence of intervention are shown in Figure 7. Most of the simulated captive populations went extinct over the 50-year period considered. Much of this risk can be attributed to a combination of demographic stochasticity (due to small population size) and inbreeding depression (arising from the close relationships of existing individuals). Extinction risk was 95%, 98% and 100% for Optimistic, Best Guess and Pessimistic scenarios respectively (see Table 3 and Figure 7).

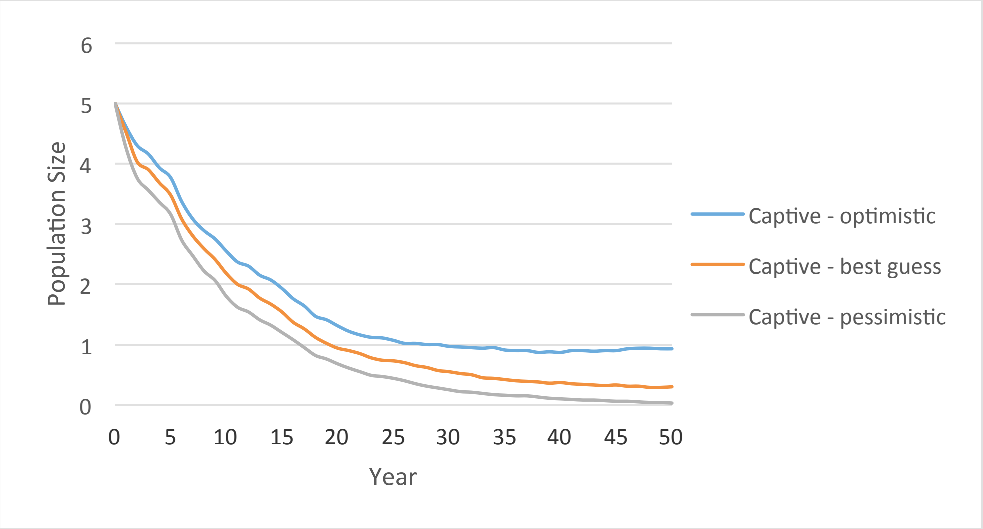

Figure 7. Captive population projections without management intervention.

Meta-population

Modeling the aggregated population across all sites (Sanctuary, Cua Dong, Hang Cai and Captivity) in the absence of any inter-site exchanges provides some insight into the projected viability of the entire species in a "business as usual" scenario. When modelled as a meta-population with no inter-site movements, the probability of extinction over 100 years was zero for the Optimistic and Best Guess scenarios but more than 10% for the pessimistic one (see Table 3 and Figure 8).

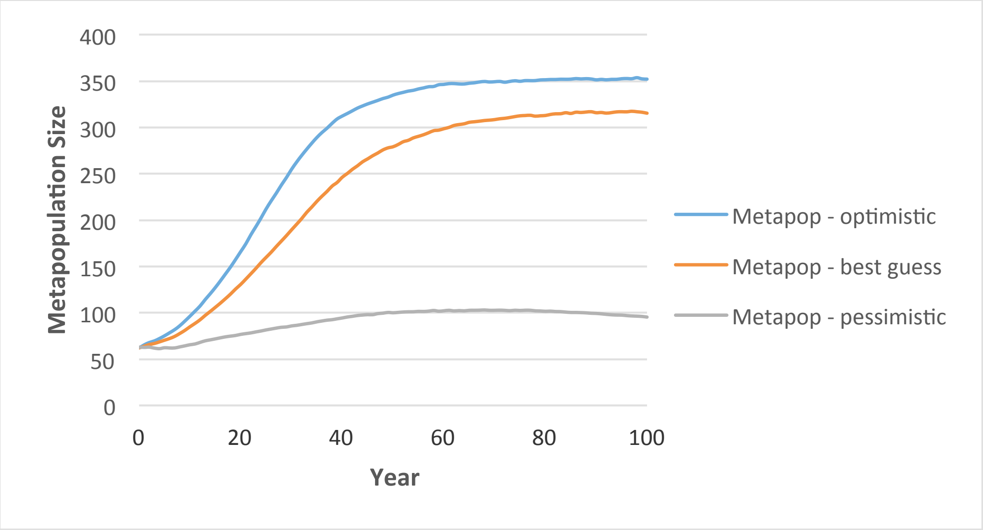

Figure 8. Meta-population projections without management intervention.

Potential Management Interventions

The following section shows the modelling results for a range of potential management interventions aimed at reducing the long-term extinction risk for the species. Firstly, the management of the entire population through regular movements of individuals is considered so as to determine the potential benefits of meta-population management. Additional scenarios focus on the five females currently isolated on Hang Cai; either translocating them to an existing wild or captive population, or introducing a male into their group. Both of these scenarios could facilitate breeding and help maintain this important genetic resource. Finally, the possible role of intensive management in reducing extinction risk in the *ex situ* population is considered.

Regular movements between sites

The potential benefits of creating, through intensive monitoring and regular movements of animals between sites, a meta-population that behaves as a single population of the same size (no genetic management is included here) is clearly illustrated in Figure 9. This is compared to the meta-population baseline in which there is no movement between sub-populations.

The interconnected meta-population outperforms the isolates in both the optimistic and best guess scenarios, confirming the benefits of connectivity. The interconnected but pessimistic scenario does not outperform the best guess and optimistic isolated sites scenarios, reinforcing the importance of the factors differentiating the pessimistic models – i.e., delayed age at first breeding, higher juvenile mortality and greater monopolisation of females by males.

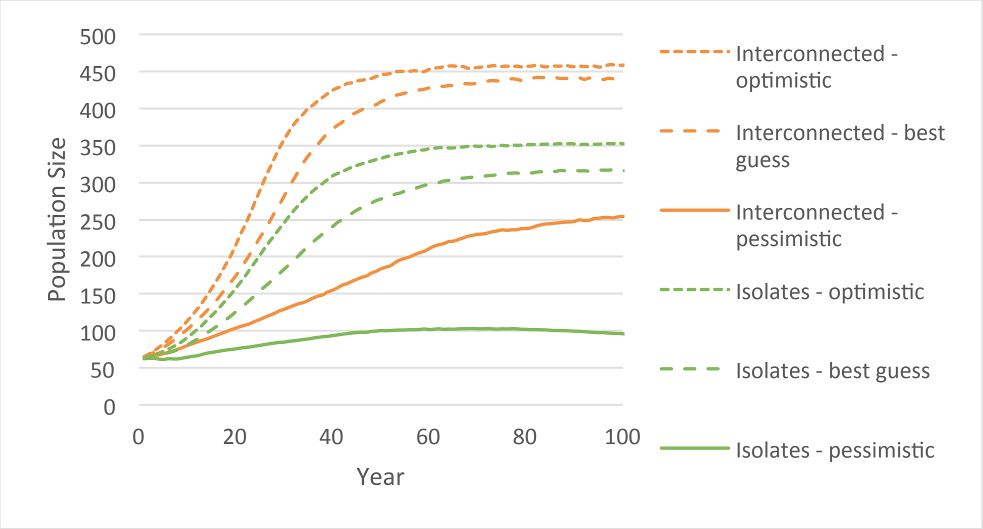

Figure 9. Comparison between an interconnected meta-population and a series of isolated sites.

Translocation of females from Hang Cai

There are five females at Hang Cai that are at least 18 years old. There is no male at that site. Table 4 considers the impact on extinction risk and average inbreeding coefficient, of translocating these five females to each of the other sites that currently hold a breeding population.

Table 4. Impact on extinction risk and inbreeding coefficient resulting from the translocation of 5 females from Hang Cai.

Site	Baseline Extinction Risk (P)*	Extinction Risk (P)* with 5 females***	Mean Inbreeding coefficient**	Mean Inbreeding coefficient** with 5 females***
Sanctuary	1.6%	0.9%	0.089	0.086
Cua Dong	8.6%	5.4%	0.144	0.135
Captive	98%	51%	0.564	0.321

All estimates come from Best Guess models
* Extinction Risk (P) calculated at 100 years for wild populations and at 50 years for captive population
** Mean inbreeding coefficient calculated at 100 years for the wild populations and at 50 years for the captive population
*** Five females added are aged at 18+ years

As can be seen from Table 4, which shows only Best Guess model results, the biggest shift in population viability comes from translocating the five females to the captive population. However, the extinction risk of this population, even with the five females, remains high (P(Extinct at 50 years) = 51%, Median time to Extinction = 47 years). That is, the captive population may not provide the most secure future for any genetic contribution these females are able to make. The second biggest impact results from transferring them to Cua Dong, although even with the five females added this population shows an extinction risk of around 5% (or 1 in 20). Note that following addition of the five females to both Cua Dong and the captive population still show an average inbreeding coefficient well in excess of 0.125. This is the inbreeding coefficient expected in offspring of matings between half-siblings and is a standardly applied maximum threshold of inbreeding applied in conservation breeding programs. Mixed scenarios where the five females from Hang Cai are split between different existing populations (either *in situ* or *ex situ*) will obviously result in smaller reductions in extinction risk to the populations they are translocated to.

Translocating all of the animals in captivity to Hang Cai was also considered though models were not constructed. Without further work on parameters the results of this scenario would be similar to those described for the scenario in which the Hang Cai females are moved to captivity, but slightly more pessimistic (the impact of inbreeding is modelled as more severe at Hang Cai than in captivity – see Appendix I). Other risk factors may also be pertinent to a comparison of these options, such as the relative risk of transferring an animal to the wild versus to captivity (including post-translocation survival and performance); and that of capturing an animal from the wild versus capturing one in captivity. Understanding these elements well enough to be able to estimate appropriate model parameters would require further discussion.

Add one male to the Hang Cai population

An alternative to translocating the five females is to leave them in place and add a male to allow them the opportunity to breed. There are two scenarios considered here:

1. Remove a male from the captive population and translocate to Hang Cai. Currently the captive population holds an 11-year-old male that is a proven breeder.
2. Remove a male from Cua Dong and translocate to Hang Cai. There is a known bachelor group in Cua Dong/Viet Hai area comprising three males.

The impact on the viability of both these potential source populations is also considered.

Pessimistic, Best Guess and Optimistic trajectories for Hang Cai plus one adult male are shown in Figure 10. Even with the addition of a male, the advanced ages of the remaining females prejudice any chance of recovery for this population, the models for which all show high extinction rates and negative growth. Extinction risk for the Hang Cai population over 100 years with the addition of one male is 84% under the Optimistic model, 93% under the Best Guess model and 100% under the Pessimistic model.

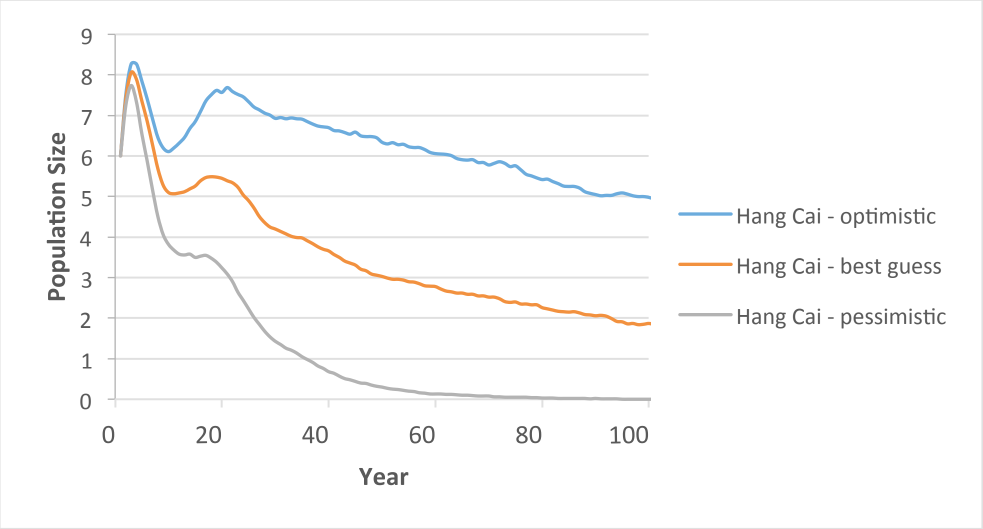

Figure 10. Hang Cai projections with one adult male added at year 1.

Remove one male from the captive population

The impact of removing the 11-year-old male from the captive population for transfer to Hang Cai is illustrated in Figure 11. There is an observable impact on growth in the captive population across all three scenarios (Optimistic, Best Guess and Pessimistic), exacerbating the already very high extinction risks. Baseline extinction risk and with the removal of the 11-year-old male is shown in Table 5.

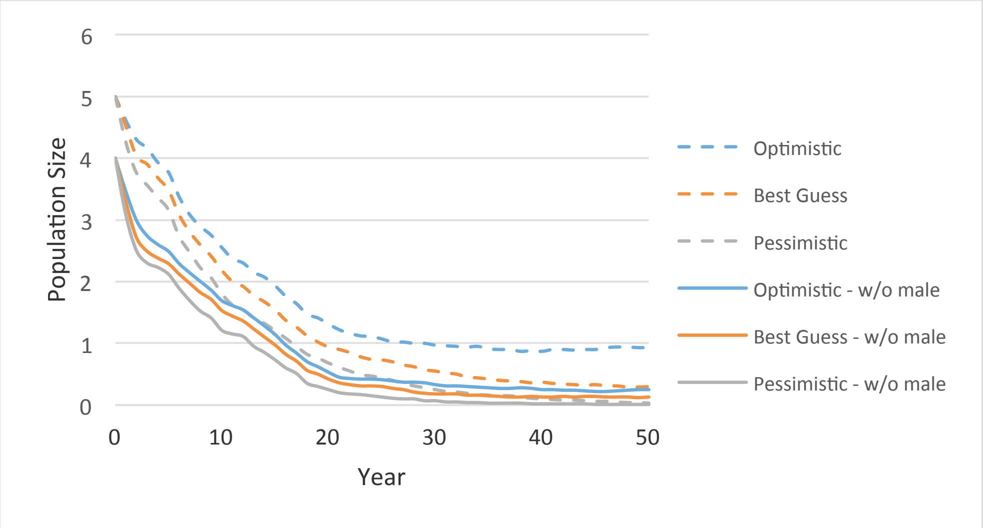

Figure 11. Impact of removing one 11-year-old adult male from the captive population.

Table 5. Expected shift in extinction risk for the captive population after removal of one 11-year-old adult male.

Model	Baseline Extinction Risk (P)	Extinction Risk without Male (P)
Optimistic	95%	98%
Best Guess	98%	99%
Pessimistic	100%	100%

Extinction Risk (P) calculated at 50 years

Remove one adult male from Cua Dong

The impact of transferring an adult male out of Cua Dong for transfer to Hang Cai is illustrated in Figure 12. As can be seen, this has little impact on the Optimistic and Best Guess scenarios but has a noticeable impact on the Pessimistic model.

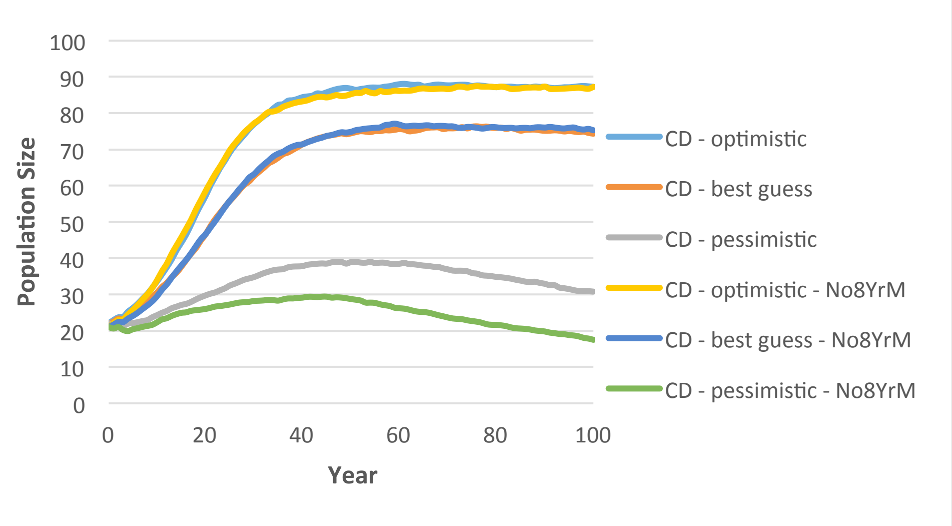

Figure 12. Impact of removing one adult male from the Cua Dong population.

Intensive Management of the Captive Population

Population management could be intensified in the captive population to enhance performance over time. Three interventions are considered: the addition of the five females from Hang Cai; the incorporation of pairing by mean kinship (i.e., prioritising pairings between individuals expected to carry rarer alleles); and reducing juvenile mortality. *[Note that the practical application of mean kinship management in langurs, as in other social species, may prove difficult and so the real life results may be more modest than the models suggest].*

The results of modelling the captive population under these scenarios is shown in Figure 13 and Table 6.

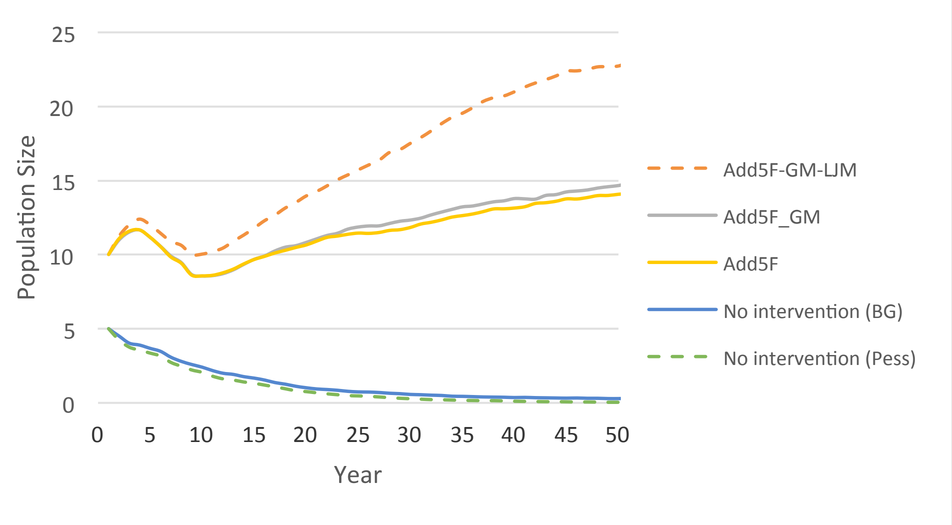

Figure 13. Impact of intensifying management of the captive population.
No intervention (Pess) = baseline model – pessimistic parameters
No intervention (BG) = baseline model – best guess parameters
Add5F = with the 5 Hang Cai females added
GM = close genetic management using mean kinship
LJM = reduced juvenile mortality.

Table 6. Extinction risk and mean inbreeding coefficients for an intensively managed *ex situ* population.

Captive Management Scenario	Extinction Risk (P)*	Mean Inbreeding coefficient**
No Mgmt – pessimistic baseline	100%	0.611
No mgmt – best guess baseline	98%	0.564
Add 5 females – best guess	51%	0.321
Add 5 females & genetic mgmt – best guess	50%	0.294
Add 5 females & genetic mgmt & low juv mortality	34%	0.273

* Extinction Risk (P) calculated at 50 years

** Mean inbreeding coefficient calculated at 50 years

As shown, there is potential for dramatically altering the prognosis for the captive population through intensive management. However, even the most ambitious scenario produces an extinction risk of 34% (roughly 1 in 3 populations go extinct over the 50-year period modelled, with a mean time to extinction of 23 years) and high mean inbreeding coefficients.

Summary of Issues for Consideration

1. The five Hang Cai females are an important resource for this species. Given their advanced age there is an urgent need to make a decision about their future and to act on that decision quickly. The modelling work to date indicates that:
    - As an isolated action, translocating a single adult male into the group at Hang Cai has a low chance of securing a future for those lineages.
    - The captive population in its current situation (too few females, too inter-related) has a low chance of providing a secure future for these linages long-term.
    - The most optimistic future for these linages is likely to derive from management actions that would involve Cua Dong and/or the Sanctuary.
2. The models indicate a high risk of extinction for the captive population even under the most optimistic management scenarios considered. Every individual is of value to the species and the current captive situation may not represent optimal application of this resource: there are too few individuals, too many males and too high a degree of relatedness amongst individuals. Captive populations can play multiple valuable roles in securing the future of a species by providing: a stable, secure environment in which populations can persist while threats elsewhere are addressed; a harvest of genetically and demographically appropriate individuals for release; ambassadors for advocacy and fund-raising; subjects for conservation-directed research. These opportunities are best provided for where the purpose of the captive population in the recovery of the species is clearly defined and understood; and where the program of management of that captive population is explicitly designed to serve that purpose. Careful consideration of the following characteristics is important:
    - Quality and consistency of husbandry.
    - Quality and flexibility of infrastructure.
    - The number of founders and their genetic and demographic characteristics.

- The growth rate, ultimate population size and rates of exchange with wild populations required to meet genetic goals (e.g., managing inbreeding below damaging levels; retain gene diversity).
- The population size required to meet demographic goals (e.g., to generate a harvest for release without detriment; to achieve ongoing stability).
- The level of genetic and demographic management intensity required to support these goals whilst accommodating the species' biology.

3. It is understood that situations on the ground often preclude proactive consideration of all of these characteristics, but the current situation provides an opportunity for review and revision of this component of the meta-population. There is a suite of commonly used tools to help with this. For example:
    a. *Vortex* – the latest version has greater capacity for projecting captive population management and for the integration of captive and wild populations.
    b. PMx – includes a suite of genetic and demographic analyses and management tools explicitly designed for captive population design and year-to-year management.
    c. SPARKS studbook software for recording pedigree and demographic information.

References

Behie, A. M., Luu Tuong Bach, Le Van Dung, Lees, C., Passaro, R., Hendershott, R., Raffel, M. and Rawson, B. M. 2014. Population status of the Cat Ba langur (*Trachypithecus poliocephalus*). *XXVth Congress of the International Primatological Society, Hanoi Vietnam, August 11-16, 2014*. Abstract #344.

Borries, C. and Koenig, A. 2008. Reproductive and behavioral characteristics of aging in female Asian colobines. *In:* Atsalis, S., Margulis, S. W. and Hof, P. R. (eds). *Primate Reproductive Aging*. Interdisciplinary Topics in Gerontology Vol. 36. Karger, Basel pp 80-102.

Borries, C., Lu, A., Ossi-Lupo, K., Larney, E. and Koenig, A. 2011. Primate life histories and dietary adaptations: A comparison of Asian colobines and macaques. *American Journal of Physical Anthropology* 144: 286-299.

Kumar, A., Solanki, G. S. and Sharma, B. K. 2005. Observations on parturition and allomothering in wild capped langur (*Trachypithecus pileatus*). *Primates* 46: 215-217.

Lacy, R. C. 1993. VORTEX: A computer simulation model for population viability analysis. *Wildlife Research* 20: 45-65.

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

Lacy, R.C. and Pollack, J. P. 2014. *VORTEX: A Stochastic Simulation of the Extinction Process. Version 10.0*. Chicago Zoological Society, Brookfield, Illinois, USA.

Luu Truong Bach and Le Van Dung. 2013. An assessment on the Cat Ba langur (*Trachypithecus poliocephalus*) in Cat Ba National Park. Unpublished Report to IUCN SSC Primate Specialist Group (PSG).

Miller, P. S. and Lacy, R. C. 2005. *VORTEX: A Stochastic Simulation of the Extinction Process. Version 9.50 User's Manual*. Apple Valley, MN: Conservation Breeding Specialist Group (SSC/IUCN).

Newton, P. N. 1987. The social organization of forest Hanuman langurs (*Presbytis entellus*). *International Journal of Primatology* 8: 199-232.

O'Grady, J. J., Brook, B. W., Reed, D. H., Ballou, J. D., Tonkyn, D. W. and Frankham, R. 2006. Realistic levels of inbreeding depression strongly affect extinction risk in wild populations. *Biological Conservation* 133: 42-51.

Qing Zhao, Borries, C. and Weshi Pan. 2011. Male takeover, infanticide, and female countertactics in white-headed leaf monkeys *(Trachypithecus poliocephalus*). *Behavioral Ecology and Sociobiology* 65: 1535-1547.

Ralls, K., Ballou, J. D. and Templeton, A. 1988. Estimates of lethal equivalents and the cost of inbreeding in mammals. *Conservation Biology* 2: 185-192.

Reed, D. H., O'Grady, J. J., Ballou, J. D., Frankham, R. 2003. The frequency and severity of catastrophic die-offs in vertebrates. *Animal Conservation* 6: 109-114.

Schrudde, D., Levelink, P. and Raffel, M. 2010. Protection fo the Cat Ba langur (*Trachypithecus [poliocephalus] poliocephalus*) through the Cat Ba Langur Conservation Project. In: Nadler, T. Rawson, B. M. and Van Ngoc Thinh (eds.). *Conservation of Primates in Indochina*. Frankfurt Zoological Society and Conservation International. Hanoi. pp 237-243.

Solanki, G. S., Kumar, A. and Sharma, B. K. 2007. Reproductive strategies of *Trachypithecus pileatus* in Arunachal Pradesh, India. *International Journal of Primatology* 28: 1075-1083.

Sommer, V., Srivastava, A. and Borries, C. 1992. Cycles, sexuality, and conception in free-ranging langurs (*Presbytis entellus*). *American Journal of Primatology* 28: 1-27.

Tong Jin, De-Zhi Wang, Qing Zhao, Li-Jie Yin, Da-Gong Qin, Wen-Zhong Ran and Wen-Shi Pan. 2009. Reproductive paramaters of wild *Trachypithecus leucocephalus*: Seasonality, infant mortality and interbirth interval. *American Journal of Primatology* 71: 558-566.

Wich, S. A., Steenbeck, R., Sterck, E. H. M., Korstjens, A. H., Willems, E. P. and van Schaik, C. P. 2007. Demography and life history of Thomas' langurs (*Presbytis thomasi*). *American Journal of Primatology* 69: 641-651.

Appendix I: VORTEX Model Parameters

Vortex Parameter	Vortex Parameter Value (Best Guess)	Vortex Parameter Value (Pessimistic)	Vortex Parameter Value (Optimistic)	NOTES	Sensitivity Testing
Species and geographic range to be modelled	Cat Ba langur (*Trachypithecus poliocephalus poliocephalus*) endemic to Cat Ba island, northeast Vietnam (Nadler and Long, 2000)	-	-		N/A
Number of populations	1 population with 3 breeding subpopulations (sanctuary, Cua Dong, Captivity).	-	-	As of August 2014 there were ~65 (60 in wild, 5 in captivity) monkeys divided into 3 breeding groups (2 wild and 1 captive), with an additional 1-2 non-breeding populations (Luu Tuong Bach *et al.*, 2013; Behie *et al.*, 2014). It is unlikely that individuals can easily immigrate/emigrate. It is unknown whether males, females, or both, emigrate at the age of sexual maturity.	N/A
Inbreeding depression included?	Yes (6.29 LEs; 50% attributed to recessive lethals)	6.29	6.29	Entered in the model as lethal equivalents imposing additional mortality on juveniles. Included at 6.00LEs to reflect more severe impact in the wild than in captivity (after O'Grady *et al.*, 2006). In any subsequent meta-population models the impact of inbreeding on captive animals can be reduced to 3.14 LEs to reflect average impact	N/A

Vortex Parameter	Vortex Parameter Value (Best Guess)	Vortex Parameter Value (Pessimistic)	Vortex Parameter Value (Optimistic)	NOTES	Sensitivity Testing
Concordance of Environmental Variation (EV) and reproduction	Yes	Yes	Yes	“Yes” indicates an expectation that good years for breeding are also good years for survival, and bad years for breeding are also bad years for survival. Answering “No” would indicate that annual fluctuations in breeding and survival are independent. If no data are available, the most conservative approach is to correlate them to avoid underestimating risk (such a correlation is typical for non-migratory species).	N/A
EV correlation among populations	N/A	N/A	N/A	This will be discussed in the context of meta-population models.	N/A
Breeding system	Polygamous - short-term	polygamous long-term	polygamous - short-term	Under “long-term” breeding systems, paired individuals are assumed to stay with their partner until one dies or emigrates. Under “short-term” breeding systems, pairs are reshuffled each year. Length of tenure for resident males of this species is unknown, although it might be similar that of white-headed langur males at 50 months (Zhao *et al.*, 2011). The range in colobines is 22–70 months.	Suggestion of Carola Borries – run with both a 2-year tenure and a 4-year tenure, as these are common for colobines

Vortex Parameter	**Vortex Parameter Value (Best Guess)**	**Vortex Parameter Value (Pessimistic)**	**Vortex Parameter Value (Optimistic)**	**NOTES**	**Sensitivity Testing**
Age of first reproduction (⍰/⍰)	7.0 years/5.0 years	8.0/6.0	7.0/5.0	This should be the average age of first reproduction, not the age of sexual maturity or the earliest age that reproduction has ever been observed. For white-headed langurs, average age at first breeding is around 5–6 years, but is based on a small sample (N=5) (Jin *et al.*, 2009). *Trachypithecus* species range from 5 years (*T. pileatus*) to 5.4 years (*T. francoisi*) with no species showing ages older than 6 based on data from more than 50 females. In the baseline, conservative values of 7 are used for males and 6 for females. This all takes body mass into account which affects life history traits.	Test at 5 and 6 for females, 6 and 7 and 8 for males.
Maximum age of reproduction	25	25	25	Other langurs can live to their mid-late 20s, and some of them (both in captivity and in the wild) do experience a senescent period of 3–9 years before death (Sommer *et al.*, 1992, Borries & Koenig, 2008). Maximum age at reproduction is set at 25 years in the baseline. This may be optimistic (one reviewer suggested 20 was more accurate) but the impact of this optimism on model projections will be determined by the values entered for age-specific mortality, which will determine the proportion of females surviving into their 20s.	Test at 20, 23, 25, 27

Vortex Parameter	Vortex Parameter Value (Best Guess)	Vortex Parameter Value (Pessimistic)	Vortex Parameter Value (Optimistic)	NOTES	Sensitivity Testing
Annual % adult females breeding	47	47	47	Birth rate in the closely related white-headed langur (*T. leucocephalus*) is reported as 0.47 ± 0.13 infants/female/year (Jin *et al*., 2009). Gestation is presumably close to the 200 days of closely related species (Kumar *et al*., 2005; Solanki *et al*., 2007; Newton, 1987; Sommer *et al*., 1992) with a range of 184 days – 210 days for Asian colobines (Borries *et al*., 2011). Interbirth interval reported as 23 ± 5.2 months (n=27) in *T. leucocephalus* (Jin *et al*., 2009) and is about two years in other closely related species. Range of interbirth intervals in Asian langurs is 16.7 months – 38.2 months (mean 22.98 months), and range in *Trachypithecus* species is 21 month – 24.5 months (mean 22.68 months) (Borries *et al*., 2011).	Test also at 15, 20 and 25% based on 3-4 infants per 17-25 adult females recently observed. Note that interbirth interval may increase as females increase in age.

Vortex Parameter	Vortex Parameter Value (Best Guess)	Vortex Parameter Value (Pessimistic)	Vortex Parameter Value (Optimistic)	NOTES	Sensitivity Testing
% males in breeding pool	Average of 3 female mates to each successful sire	4	3	Because groups form single-male, multi-female groups, there are likely to be all-male groups that do not breed. Generally speaking in langurs, these groups act to depose males in breeding groups with subsequent replacement by the dominant male from the all-male group. We have one bachelor group in Cua Dong, suggesting this does occur in the wild populations. In captive scenarios this is not relevant. Value entered in the baseline is an estimate of the average number of mates per successful sire (Vortex will use this value to calculated the % of males in the breeding pool).	ST at 4 and 5 based on group sizes recently observed.
Litter size	1	1	1	At most, one infant per female per 1-2 years	
Offspring sex ratio (% males)	50%	50%	50%	Unknown but likely to be 50:50. Based on the small number of juveniles in Cua Dong (N = 6) we have a 50:50 sex ratio.	Sensitivity test at 60:40 and 55:45

Vortex Parameter	**Vortex Parameter Value (Best Guess)**	**Vortex Parameter Value (Pessimistic)**	**Vortex Parameter Value (Optimistic)**	**NOTES**	**Sensitivity Testing**
EV in breeding (measured as standard deviation of breeding females)	13	13	13	Unknown on Cat Ba but studies of birth rate data for *T. leucocephalus* (Jin *et al*., 2009) indicate overall birth rate of 0.47 ± 0.13 infants/female/year; i.e., a birth rate in a good year of 0.6 infants/female/year and in a bad year of 0.34 infants/female/year.	Based on real data interpreted as a sample from a normal distribution (i.e., in the model, in 67% of years the % of females breeding during the year will be between 34% and 60%; 95% of the time it will be between 21% and 73%, etc.).
% annual mortality (⍰/⍰)	SD= 20% of mean	SD= 20% of mean	SD= 20% of mean	Based on data from other langur species (above) and expert opinion. See Male_female_Mortality sheet for an illustration of the shape of age-specific mortality created by these values. For mortality, collaborators had data and some confidence with respect to Cat Ba Langur values for the 0–1 and 1–2 year age-classes. These are varied across the three baselines - 15 - 20 - 25% All other values remain the same across baselines and were derived from a combination of Cat Ba Langur data observations and published data for other species. A full set of age-specific mortality rates *for P. thomasi* were available (Wich *et al*., 2007) based on a 15-year study (these rates produced a lambda value of 1.01).	Note: females die in higher percentages in the first few years, and then survive in higher percentages once adults. Opposite appears to be true in captivity.

Vortex Parameter	Vortex Parameter Value (Best Guess)	Vortex Parameter Value (Pessimistic)	Vortex Parameter Value (Optimistic)	NOTES	Sensitivity Testing
				Collaborators agreed that these mortality rates were too high for Cat Ba Langurs, but that the difference between male and female rates might be similar. Therefore, all three baseline models begin with estimated values for female age-specific mortality agreed by collaborators. Male values are then derived from those using the *P. thomasi* male:female differential in rates.	
0–1 years	12.5/14	20/22	10/11	15% based on data from *T. leucocephalus* Wild *P. thomasi* – male infant mortality 48%, female infant mortality 43% (Wich *et al*., 2007). In wild populations with sexes pooled the following is seen: *T. cristatus*: 30% for different populations, *T. leucocephalus*: 15% (Jin *et al*., 2009), *T. phayrei*: 16%. Mortality to one year (sexes combined as no difference - 12.5%)	
1–2 years	14/16	20/23	10/12	*T. phayrei* mortality (both sexes pooled) from 1–2 years is 14%. When sexes are pooled and we consider mortality from birth to 2 years of age, the following is seen: Wild populations (*T. leucocephalus* 15.8% (females), 12.3% (males); *R. roxellana*: 22.4%, *R. bieti* 55-60%).	
2–3 years	15/36	20/48	10/24	Wild *P. thomasi:* 20% (females), 26.7% (males) Wild *T. phayrei* (sexes combined) mortality at 2–3 years is 15%.	

Vortex Parameter	**Vortex Parameter Value (Best Guess)**	**Vortex Parameter Value (Pessimistic)**	**Vortex Parameter Value (Optimistic)**	**NOTES**	**Sensitivity Testing**
3–4 years	3/4	3/4	3/4		
4–5 years	3/9	3/9	3/9		
5–6 years	2/12	2/12	2/12		
Adults (females)	2+((A>15)*8)+((A>20)*20)	2+((A>15)*8)+((A>20)*20)	2+((A>15)*8)+((A>20)*20)	Wild *P. thomasi*: 7% annual adult mortality for females, 17.1% for males; Captive *T. cristatus*: 50%	
Adults (males)	5+((A>15)*21)+((A>20)*52)	5+((A>15)*21)+((A>20)*52)	5+((A>15)*21)+((A>20)*52)	Wild *P. thomasi*: 7 % annual adult mortality for females, 17.1% for males; Captive *T. cristatus*: 50%	
Density Dependence	Not included in the baseline model	-	-		

Vortex Parameter	**Vortex Parameter Value (Best Guess)**	**Vortex Parameter Value (Pessimistic)**	**Vortex Parameter Value (Optimistic)**	**NOTES**	**Sensitivity Testing**
Initial population size	65 (All groups, 60 in wild and 5 in captivity)	-	-		
Carrying capacity	50 in captivity 100 in Cua Dong 280 in Sanctuary	-	-	No firm estimates of carrying capacity have been developed yet but the model requires that a figure be entered. The population is currently thought to be significantly below carrying capacity. For captive scenarios the current estimate is 50 individuals given limitations of infrastructure and costs to house any more. For wild animals in Cua Dong, the estimate is 100 animals given that the area included (based on ranging of the bachelor group) would include the Peninsula around to close to Cat Ba town and up to Viet Hai. For the Sanctuary, data suggests that a population density of 20 animals/km² could be sustained, which equates to about 280 animals. We are assuming no shift in carrying capacity over time, although habitat continues to be lost due to construction and fragmentation (Schrudde *et al*., 2010) we will assume that habitat can be stabilised in key areas.	Run a carrying capacity of 50 animals in Cua Dong to see what if any difference this makes

Vortex Parameter	Vortex Parameter Value (Best Guess)	Vortex Parameter Value (Pessimistic)	Vortex Parameter Value (Optimistic)	NOTES	Sensitivity Testing
% transfer rates	N/A	-	-		
Breeding pair selection	Random	-	-		
Genetic management	Not included in the baseline model	-	-		
Catastrophe	Loss of 50% of population once every 90 years	-	-	Reed *et al.* (2003) examined data for wild populations of 88 vertebrate species and concluded that the probability of a severe catastrophe (defined as a loss of 50% of the population in one year) across all causes was 14% per generation, or about once every 7 generations.	
Poaching (increase in adult mortality)	N/A	-	-	Not included	Not included
Supplementation	N/A	-	-	Not included	Not included
Time frame	50 years captivity 100 years wild	-	-	Long-lived species – actions taken now can have long-term impacts. Shorter timeframe will allow us to better understand management scenarios	?