Working together to conserve biodiversity in national parks and nature reserves in Viet Nam.

PVA REPORT: THREATENED SPECIES OF THE ANNAMITE RANGE

Report prepared for Re:Wild by the IUCN SSC Conservation Planning Specialist Group. It covers preliminary population model assembly and viability analyses for a subset of threatened species native to the Annamite Range. These species are the focus of a larger re-wilding effort. Data were collected and models designed through a series of virtual workshops with relevant specialists.

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Photo Credit: Hans-Werner Hermann

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POPULATION VIABILITY ANALYSES FOR THREATENED SPECIES OF THE ANNAMITE RANGE

Introduction

The "Annamite Range" is a major mountain range of eastern Indochina, extending approximately 1,100km through Laos, Vietnam, and a small area in northeast Cambodia.

Re:wild is working with partners to conserve a group of threatened species endemic to the Annamite Range (see Table 1). One focus of Re:wild's work is the use of *ex situ* management to accelerate the re-establishment or recovery of targeted species, at sites where major threats (mainly snaring) are effectively managed. This approach will break new ground for some, or all, of the species targeted and therefore all efforts are being made to understand the potential challenges and to plan to address them where possible.

Table 1. Species included in the 2021-2022 population viability analyses project. Grey shading indicates species whose analyses are not yet started.

1	Saola	*Pseudoryx nghetinhensis*
2	Large-antlered Muntjac	*Muntiacus vuquangensis*
3	Dark Muntjac	*Muntiacus rooseveltorum*
4		*Muntiacus truongsonensis*
5		*Muntiacus puhoatensis*
6	Owston's Civet	*Chrotogale owstoni*
7	Annamite Striped Rabbit	*Nesolagus timminsi*
8	Sumatran Striped Rabbit	*Nesolagis netscheri*
9	Vietnam Pheasant	*Lophura edwardsi*
10	Crested Argus Pheasant	*Rheinardia ocellata*
11	Grey Peacock Pheasant	*Polyplectron bicalcaratum ghigii*
12	Impressed Tortoise	*Manouria impressa*
13	Bourret's Box Turtle	*Cuora bourreti*
14	Keeled box turtle	*Cuora mouhotii mouhotii*
		Cuora mouhotii obsti
15	Eastern Black-ridged Leaf Turtle	*Cyclemys pulchristiata*
16	Big-headed Turtle	*Platysternon megacephalum*
17	Four-eyed Turtle	*Sacalia quadriocellata*
18	Wattle-necked Softshelled Turtle	*Palea steindachneri*

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The following pages document Population Viability Analyses (PVA) undertaken by the IUCN Species Survival Commission (SSC) Conservation Planning Specialist Group in collaboration with experts with knowledge of the species or of the wider rewilding program. These analyses aim to support conservation planning efforts by: 1) providing general insights into the strengths and weaknesses of each species' situation (including biology and current circumstances); 2) providing estimates of the performance of these species under different captive and wild conditions; 3) providing well-documented PVA models that can be used as an ongoing tool for managers; and 4) identifying important data gaps.

This is a preliminary PVA report. The different species projects included in these analyses are highly varied in terms of: how much is known about the species; how much existing *ex situ* experience there is; and how much planning and preparation has already taken place for the *ex situ* and *in situ* project components. With the time and resources available it was not possible to bring all the species' PVA analyses to the same point. This preliminary report documents progress to date with each project, so that analyses can be easily picked up and further developed as needed.

Scope

Taxonomic: the PVA project covers 18 taxa. Two are not yet started (shown in grey in Table 1).

Geographic & operational: analyses explored population performance at wild sites in the Annamites, and at *ex situ* facilities primarily in Vietnam as well as in Europe and North America for some taxa.

Timeframe: for most taxa it was agreed that a 50-year timeframe for projections struck a reasonable balance between maintaining operational relevance and being able to discern likely longer-term population trends. For some longer-lived taxa (turtles) this was extended to 100 years.

Modelling Questions

The taxa considered in these analyses vary widely not only in their biology but in their current circumstances and opportunities for conservation management. Some are presumed to be extinct in the wild, others are still present in numbers large enough for wild collection to be feasible; some have been successfully bred in captivity, others have not; some are regularly confiscated in large numbers from the illegal trade, others are not. Despite these differences some of the fundamental challenges to establishing viable populations at wild sites, using individuals translocated from *ex situ* facilities, are similar. Consequently, though the analyses are modified for each case, there are some common elements to the structure of the models and to the kinds of questions posed, and these are outlined in Figure 1. below.

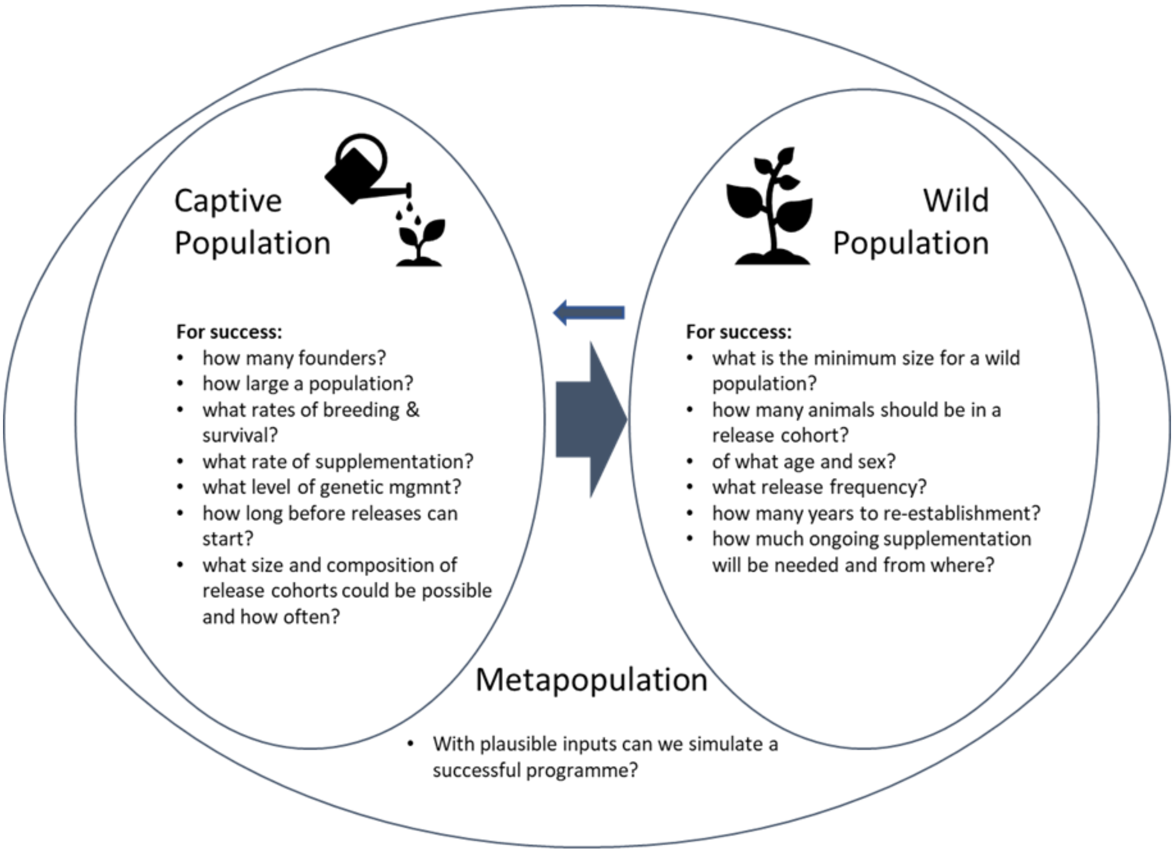


Figure 1. Illustration of the conceptual model underlying each species analysis, showing a metapopulation with captive and wild population components, and movement between the two. Blue arrows indicate the expected direction and relative magnitude of animal movements.

In addition to helping to answer the questions described in Figure 1., models can help identify the areas of uncertainty in the available information that have the most impact on outcomes and, therefore, that could be included among the priorities for further investigation.

Population Viability Analysis (PVA) and VORTEX

PVA tools help us to use information about past population trends to project forward likely future trends under different circumstances or types of management. This can help discussions about which practices may be the most effective in achieving specific conservation goals.

VORTEX, a simulation software package written for PVA (Lacy et al. 2005; Lacy et al. 2017), is specifically designed for this purpose and was used throughout these analyses. The VORTEX package is a simulation of the effects of several different natural and human-mediated forces – some, by definition, acting unpredictably from year to year – on the health and integrity of wildlife populations. VORTEX treats population dynamics as discrete sequential events (e.g., births, deaths, dispersal between populations, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modelled as constants or random variables that follow specified distributions. The package simulates a population by recreating the essential series of events that together describe the typical life cycles of sexually reproducing organisms. See Figure 2. for a generalised diagram of a typical annual life cycle (or timestep) as simulated in VORTEX.

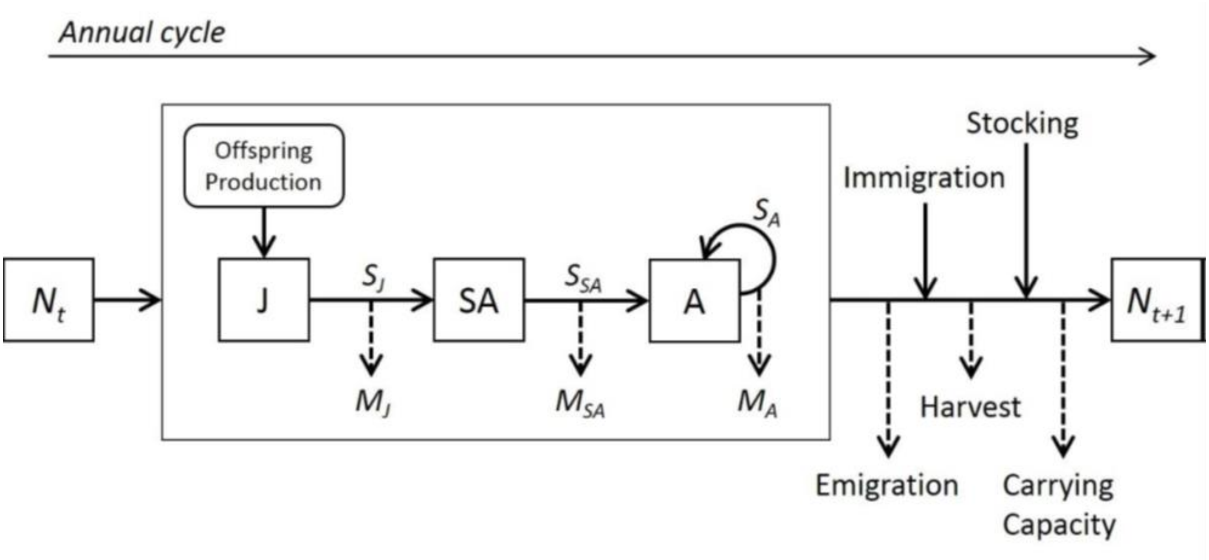


Figure 2. General schematic diagram depicting the series of events making up a typical annual cycle (timestep) in the PVA modelling software package VORTEX, representing simulated change in population abundance from *Nt* to *Nt+1*. The enclosed portion of the diagram shows the production of juveniles (J) and the transition of individuals among the juvenile, subadult (SA) and adult (A) stages, determined by annual age-specific survival (*Sx*) rates and their complementary mortality (*Mx*) rates. On the right side of the diagram, processes above the timeline act to increase population abundance, while those below the timeline decrease abundance. The aggregate effect of these various demographic processes results in a new population abundance at the end of the timestep. For more information on VORTEX, see Lacy et al. (2017).

Cautionary Note

Population viability analyses such as those described in these pages will not give absolute and accurate "answers" for what the future will bring for a given wildlife population or programme of management. This limitation arises partly from our inevitably incomplete knowledge of the complex systems we are aiming to model, and partly from our inability to identify and quantify accurately the future influences on those systems, either natural or human mediated. Consequently, many researchers have cautioned against the exclusive use of PVA results in promoting specific management actions for wildlife populations and this advice is reiterated here (e.g., Ludwig, 1999; Beissinger and McCullough 2002; Reed et al. 2002; Ellner et al. 2002; Lotts et al. 2004; Lacy 2019).

Despite these limitations, PVA tools such as VORTEX are valuable in helping to structure the assembly and critical analysis of relevant information and in providing an objective means for comparing the expected performance of a population under different circumstances. This process can help groups to converge on a collective decision about the most appropriate way forward for management and to document clearly the assumptions made when reaching this decision, as well as providing a framework for reviewing and improving key information gaps and integrating new information into the collective understanding of population dynamics.

Process of Model Development

For each taxon modelled, captive data were gathered wherever possible, from regional or international studbooks either for the target taxon or for an appropriate analogue species. These data were reviewed and validated as a collective "best guess" by a team of relevant experts. Where appropriate studbooks did not exist or were not available, values were elicited directly from the expert group. As few wild data exist for these species, captive models were used as a starting point in each case and were then modified by the same experts, to create plausible models of each taxon under wild conditions.

Stage 1: Problem Definition. Describing the context of the modelling exercise, the current situation of the species (both wild and captive) and the main questions to be informed by the models.

Stage 2: Constructing and Verifying Baseline Models. Calculating and estimating model parameters to build Baseline Models from which various management scenarios can be built and tested. Verifying the Baseline Models to ensure that they are biologically plausible and a reasonable representation of what has been observed for the species.

Stage 3. Conducting Sensitivity Analyses. Testing the sensitivity of the models to plausible parameter variation, to identify those that have the most impact on population performance and to confirm priorities for resolution of parameter uncertainty.

Stage 4. Testing Management Scenarios. Building different models to emulate alternative management scenarios or situations and comparing their performance.

Stage 5. Interpreting Model Results. Interpreting and discussing the modelling results in the context of the questions posed accounting for the limitations of the models.

These baseline captive and wild models were then further modified on advice from the expert groups, to emulate different management strategies of interest. In the following pages the results of these analyses are documented for each taxon covered in the analysis.

Model Performance: Indicators and Measures

To enable comparisons to be drawn across model scenarios, some or all of the following measures are tracked and reported for each scenario:

- **P(Ex)** - extinction risk over the timeframe considered;
- **Stoc-r** - instantaneous rate of growth;
- **GD** - gene diversity or expected heterozygosity;
- **N-All** - mean population size across iterations, including those that resulted in extinction;

- **N-Extant** - mean population size across iterations excluding those that resulted in extinction;
- **I** – mean inbreeding coefficient or observed homozygosity across the population.

For further explanation of these standard VORTEX outputs, see Miller & Lacy (2005).

Unless otherwise indicated, the following threshold values are used to draw a distinction between more and less successful scenarios:

Measure	**"Success" threshold**	**Rationale/explanation**
P(Ex)	0.000	No simulations go extinct over the period.
Stoc-r	≥ 0.000	Populations are not declining.
GD	90%/95%	Commonly agreed threshold flagging potentially damaging loss of genetic diversity, used for captive/wild populations (Soulé et al., 1986; Frankham et al. 2002).
I	0.125	Commonly used in the management of captive populations to flag potentially damaging inbreeding accumulation (e.g.Frankham et al. 2002)
N-All	Various	Scenario-dependent.
N-Extant	Various	Scenario-dependent.

Minimum Viable Population Size is defined here as the minimum population size that confers an extinction risk of 1% or less over 100 years, unless otherwise specified.

General Information and Assumptions

For most of the taxa considered in these analyses both captive and wild population models (as well as metapopulation models) were constructed. For the captive models it was possible to obtain at least some data from *ex situ* populations either for the target taxon or for analogue species, and wherever possible the observed performance of those *ex situ* populations was used to validate the plausibility of the models constructed.

For the wild models there were no directly relevant population data. Therefore, in most cases, the captive models were used as a starting point and customised using advice from experts and the literature, to emulate the likely response of the species to wild conditions. Typically (though not in all cases):

- inbreeding severity was increased to reflect the increased stresses on individuals in the wild (O'Grady 2006);
- longevity was reduced and early mortality increased, to reflect increased exposure to mortality factors and absence of veterinary intervention;
- polygynous social systems were restored in naturally polygynous species for which monogamous pairings are preferred in captivity for ease of management or improved genetic outcomes.

Other variations are described in the species sections.

Wild site carrying capacity

In addition to factors related to species biology, wild models need to account for site-specific factors including species carrying capacity and the severity of specific threats. These can be expected to vary among wild sites and can have a considerable impact on modelled population performance.

Carrying capacity is used here to mean the maximum number of animals that a modelled population or "site" can support. At the end of each year of a simulation, where the population size has exceeded carrying capacity, additional mortality is imposed randomly across age-classes, at a rate expected to remove the excess. With more data or informed assumptions, it would be possible to model more subtle density dependent dynamics.

Sire-specific carrying capacities for the models can be estimated by:

- Calculating the likely area of occupancy of the species, for each site, based on known or assumed habitat preferences.
- Estimating the minimum and maximum densities of each species in preferred habitat.
- Combining these two pieces of information to create a range of carrying capacity estimates for each site, that can be used in the models to provide best and worst-case scenarios.

The species in this project have not been well studied in the wild, some have not been observed there for many decades, and for some there are few historical observations. Given the paucity of data and the difficulty of making estimates about habitat preferences and densities for species about which so little is known, site-specific carrying capacity estimates are not included here. Instead, a range of generic values is used (i.e. non-site-specific) designed to illustrate the relationship between species viability and carrying capacity, under varied levels of snaring pressure. These general findings can be used to evaluate the suitability of different sites, as further information is gathered about them, and about likely species preferences and tolerances.

Wild site snaring intensity

At the wild sites of interest, indiscriminate snaring is considered the biggest threat to all species except for the turtles, which are not impacted by snares, but are impacted by intensive collection effort. There are no species-specific data on the annual number or percentage of individuals taken by snares or collection at individual sites. However, risks are expected to vary between sites as some are the focus of intensive de-snaring operations. The Vietnam Pheasant Recovery Team is currently analysing camera trap data for a subset of sites, which may shed further light on the issue for this species. In absence of site-specific data, the impact of snaring or collection on wild populations of affected species was tested across a range of 10-90% population offtake per year.

OVERVIEW OF SPECIES MODEL PERFORMANCE

The following thumb-nail graphics provide a summary and inter-species comparison of the captive and wild models, as they have been developed so far.

Baseline Captive Models: assume a founder population of 20 individuals and a total carrying capacity (adults and young) of K=100.

Harvest Models: assume a captive population of 50 individuals and an annual harvest of all individuals in excess of carrying capacity.

Baseline Wild Models: assume a founder population of N=15 and a carrying capacity of K=100.

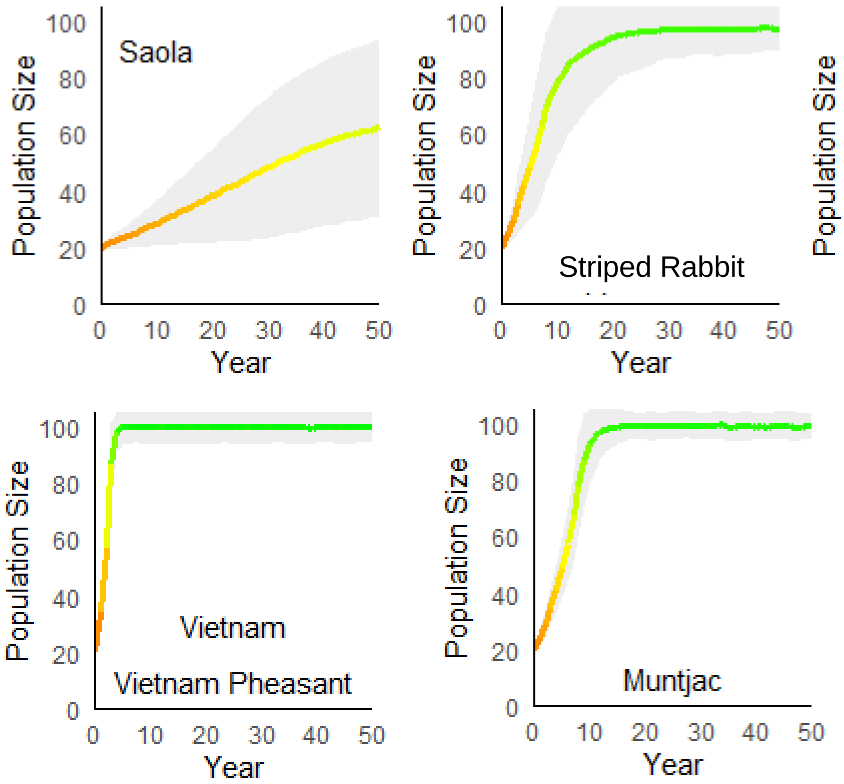
Summary of Findings

Baseline Models (Captive): Most captive models, as currently built, grow strongly from 20 founders to carrying capacity (K=100) and remain there for the 50-year period with little fluctuation. One exception is Saola, for which deliberately conservative values were set in the models to reflect expected early husbandry challenges and the likelihood that remaining wild stocks might exhibit lowered fitness. Other exceptions are five of the turtle species (*C. trifasciata*, *M. annamensis*, *M. impressa*, *P. megacephalum* and *R. swinhoei*). As for Saola, population models for these species fluctuate over time, sometimes dramatically enough to result in extinction. Further work is needed to explore feasible management scenarios that result in more reliable growth.

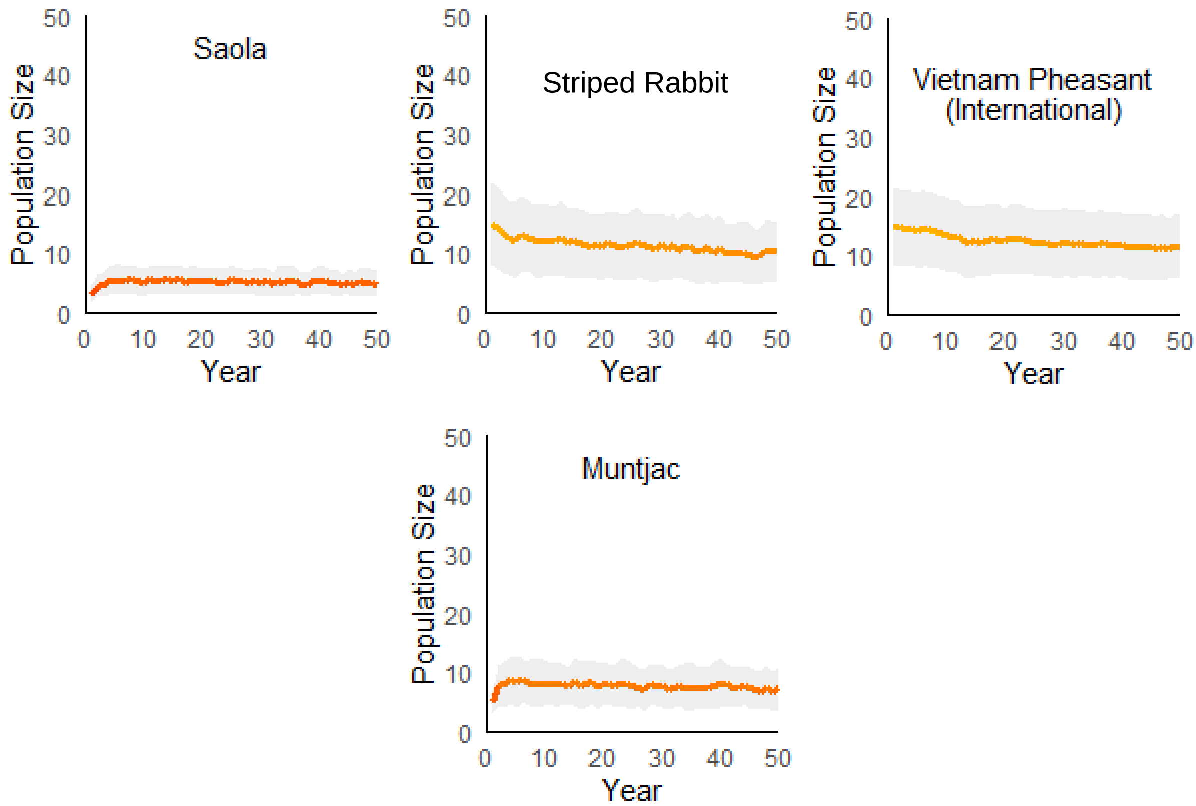
Potential annual harvest for release to the wild: Annual harvest capability ranges between 5 and 25 individuals per year depending on the species but is most often around 5-10. For shorter-lived species there is an observable decline in harvest size over time resulting from inbreeding accumulation. For the species listed above for which growth rate is weak and highly variable, little or no harvest is possible.

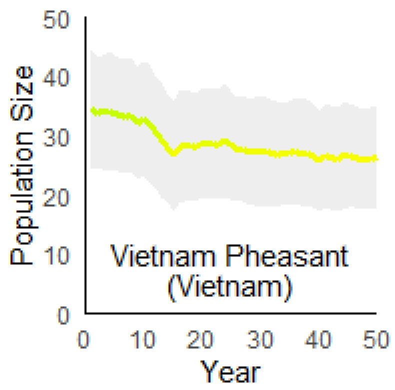
Baseline Models (Wild): Very little is known about the species in this modelling exercise. For captive models, values were often inferred from data for similar species. However, no such data were available for equivalent species in the wild, under the conditions expected in the Annamites, and so wild models are not yet built for all species. With the values estimated for mammals and birds, wild models grew well. However, best estimates of turtle dynamics post-release delivered only one growing population (for *P. steindachneri*) and further work is needed to determine a feasible pathway to growth in a reintroduced turtle population in the Annamites.

Mammals & Birds: Baseline Models (Captive)

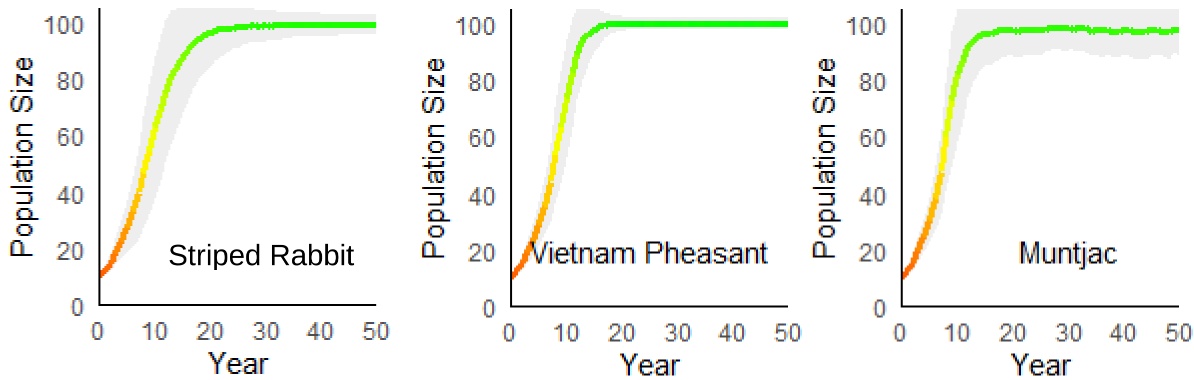


Mammals & Birds: Potential Annual Harvest for Translocation to the Wild

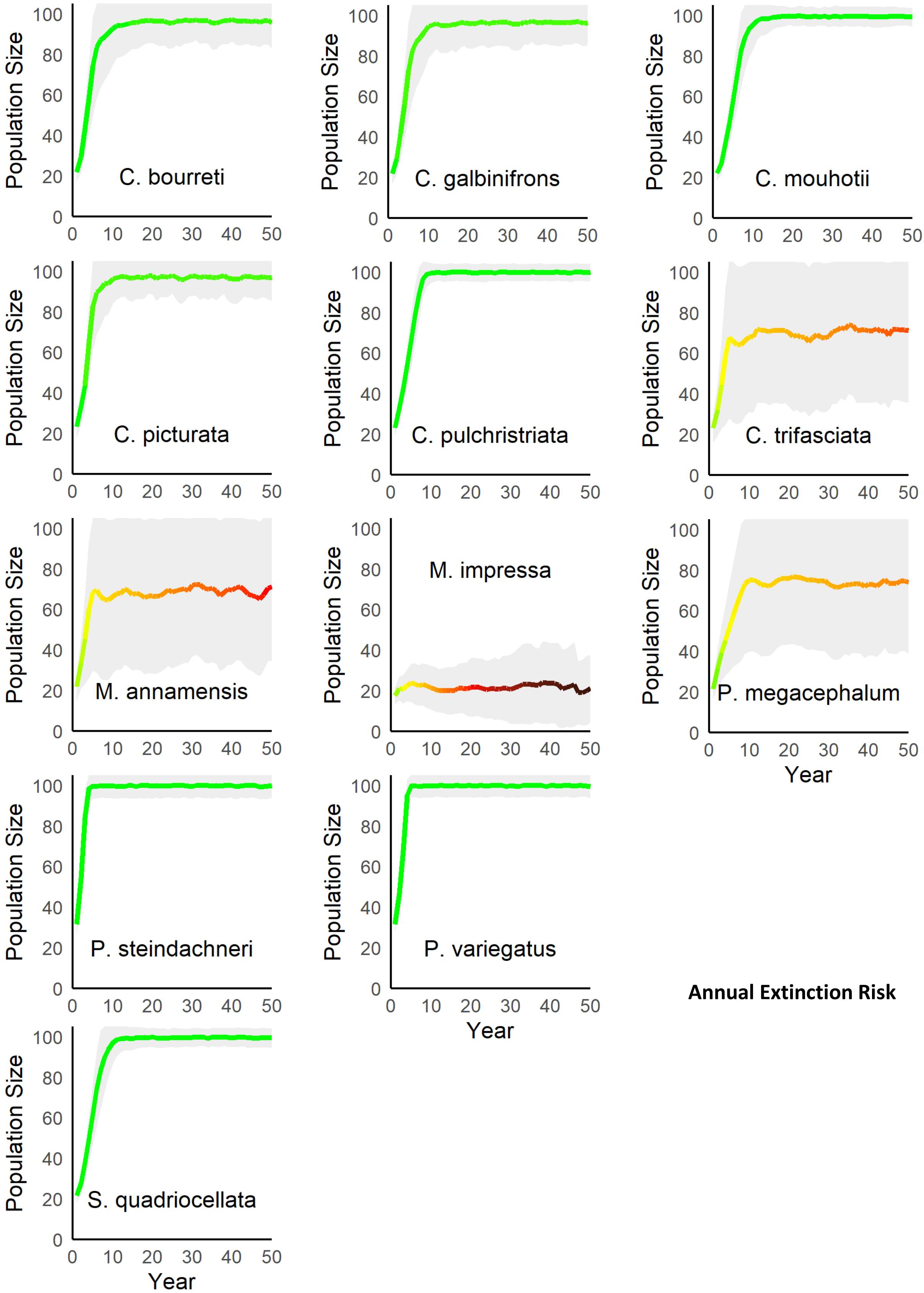


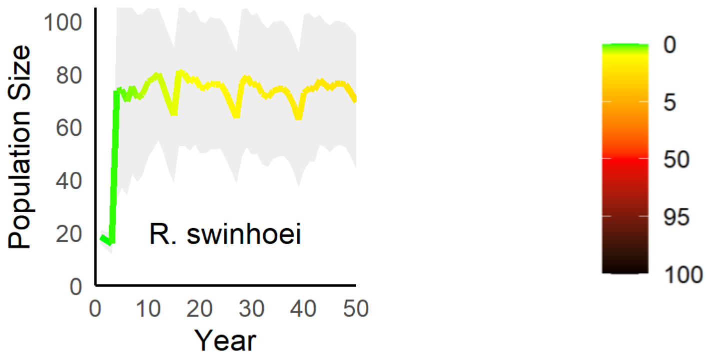


Mammals & Birds: Baseline Models (Wild)

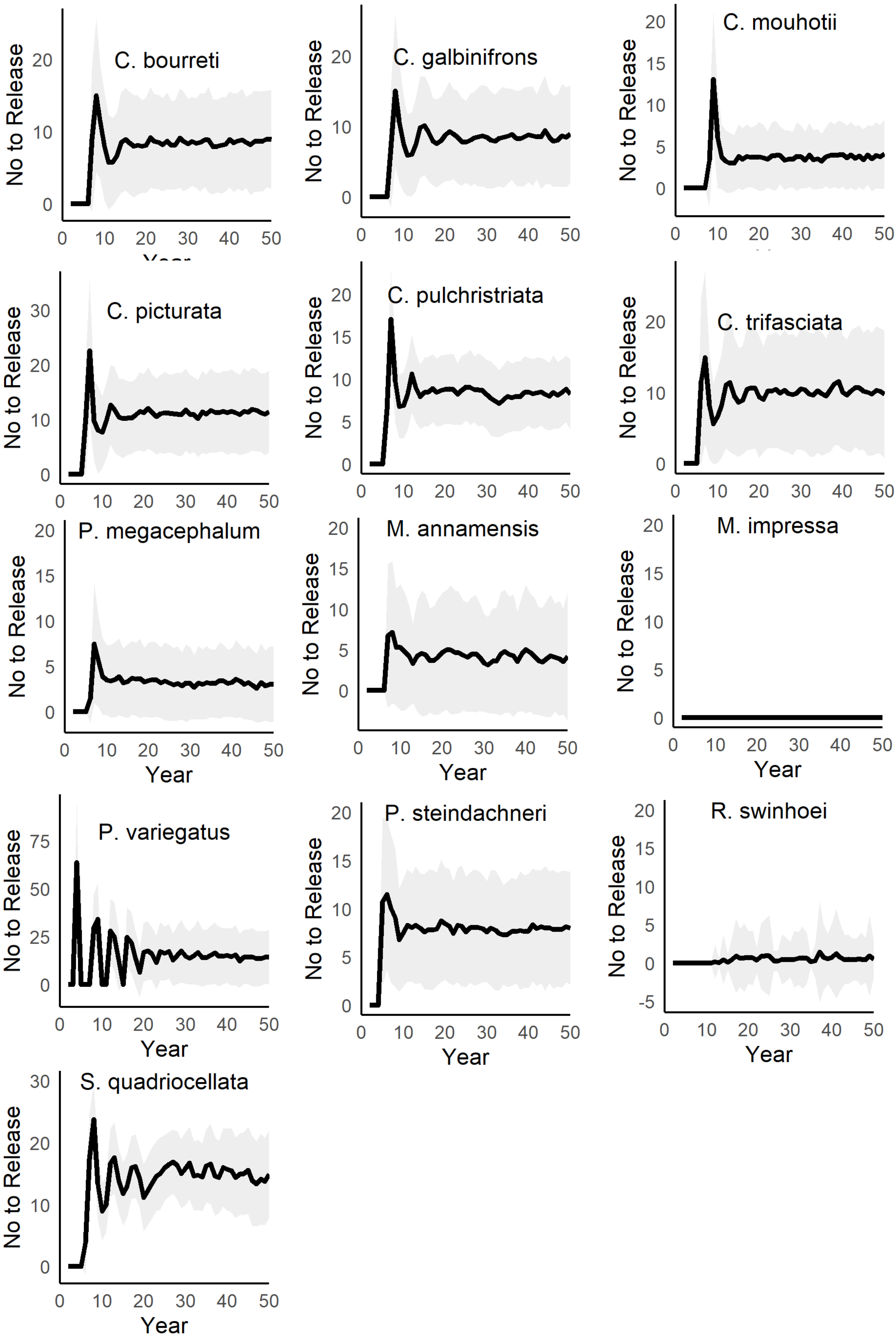


Turtles: Baseline Models (Captive)

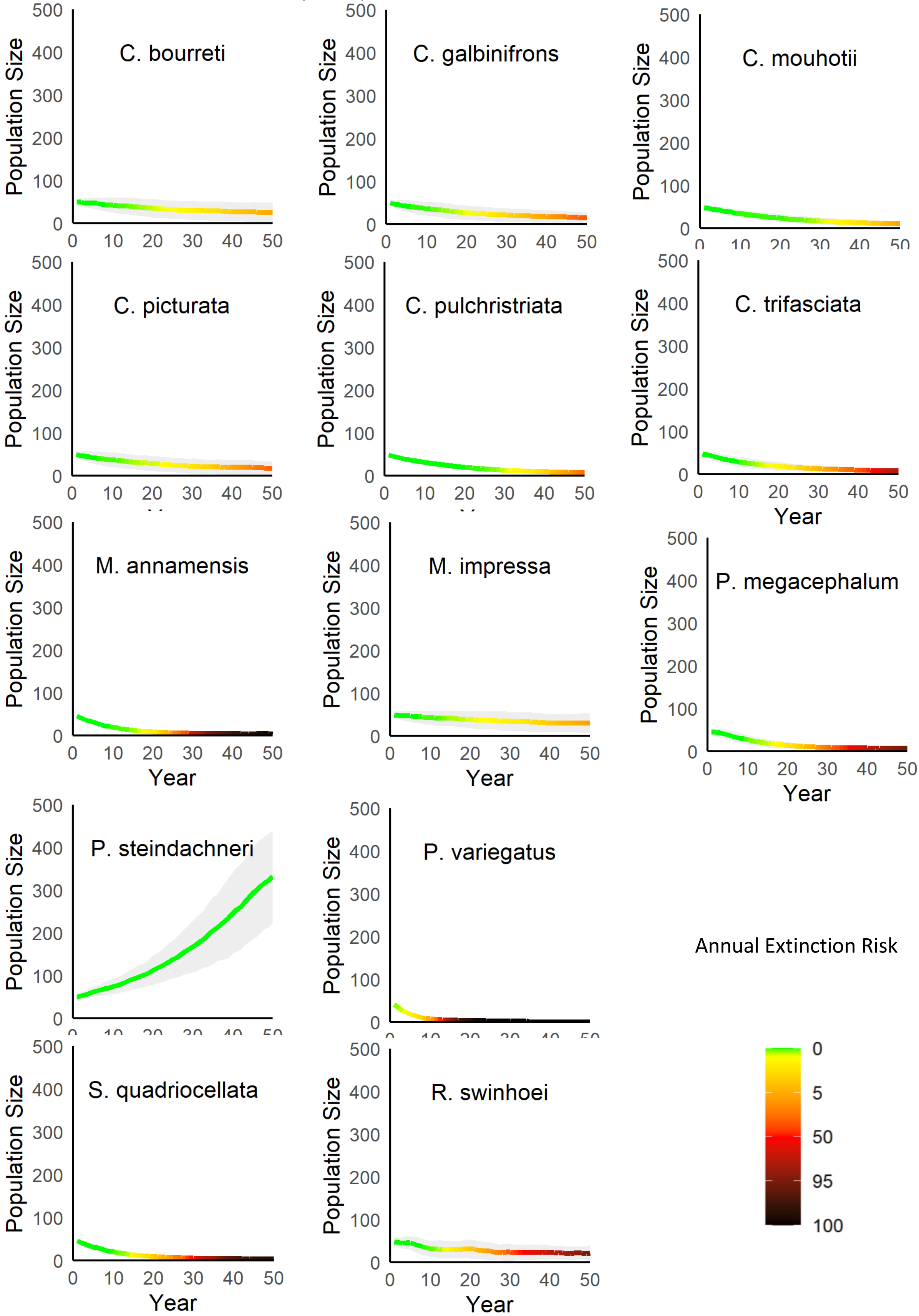



Population Size
100
80
60
40
20
0
R. swinhoei
0
10
20
30
40
50
Year
0
5
50
95
100

Turtles: Potential Annual Harvest for Translocation



Turtles: Baseline Models (Wild)



SAOLA

Introduction

The Saola, *Pseudoryx nghetinhensis*, has been known to Western science only since 1992 when it was recorded from North-Central Vietnam. Saola, are small forest-dwelling bovines, native to evergreen forests of Vietnam and Laos PDR. Individuals have been encountered only rarely in the wild and the species is considered Critically Endangered by the IUCN. Primary threats are deforestation for agriculture and infrastructure building, which both reduces and fragments available habitat as well as increasing access to untouched forest by hunters.

The current conservation plan for Saola includes the capture of individuals from the wild and their management in secure captive facilities within Vietnam where, ideally, they would grow to provide a secure insurance population and, eventually, individuals for release to protected wild sites. Given so few sightings in recent years the likelihood of achieving this is considered by PVA contributors to be extremely low.

Summary of Findings to Date

For a successful captive model	Findings	Notes
How many founders?	Not open to management.	0-5 considered plausible range of founder availability – not enough for "success" under the definitions used.
How large a population?	Not open to management.	For the expected founder baseline and management challenges, a facility for 50 Saola (for example) would be unlikely to reach capacity over 50 years.
What rates of breeding & survival?	High rates required for any chance of success.	These factors are over-shadowed by stochastic events due to the likely small founder base.
What rate of supplementation?	Not considered.	Ability to supplement is not anticipated.
What level of genetic management?	Growth a priority for the foreseeable future.	Breeding as often as possible from as many animals as possible is the intended initial strategy –pairings between close relatives is likely to be unavoidable.
How long before releases can begin?	Uncertain.	Models show few successful trajectories with the founder base anticipated. Among these, time to harvestable size varies by decades within the 50-year period.
What size, composition & frequency of release cohorts could be possible?	Uncertain.	Not relevant at this time given the poor prospects of establishing a successful programme.

For a success wild model	Findings	Notes
What is the minimum viable population size?		Further work on this awaits developments in the wider Saola programme.
How many animals should be in a release cohort?		
Of what age and sex?		
What release frequency?		
How many years to re-establishment?		
How much ongoing supplementation will be needed and from where?		
Meta-population question		
With plausible inputs can we create a successful scenario?	Not at present. Estimates of the likelihood of successfully capturing enough founder individuals are currently too low.	

Captive Baseline Model

A Baseline Model was constructed to emulate the dynamics of a hypothetical captive population in Vietnam under plausible conditions. No population data are available for this species, which has never been managed in captivity or studied in the wild. Of the ungulate data sets available the International Studbook for Lowland Anoa (Nortzold & Alaze, 2020), was considered most likely to provide reasonable analogue data and demographic parameters from this were used as a starting point. Analysis and interpretation of data exported from the Lowland Anoa studbook and information about the intended management of the Saola captive population, which is not yet established, were provided by J. Andrews and J. Holland respectively. Baseline Model parameters and the accompanying rationale are shown in Table 3.

Table 2. Captive Baseline Model Parameters for Saola, *Pseudoryx nghetinhensis*

VORTEX Parameter	Baseline Model Value	Rationale
Period modelled	50 years	Default for this project. Represents approximately 6 generations of Saola.
Inbreeding depression severity (entered as lethal equivalents)	3.14	VORTEX default, based on studies of captive mammals (Ralls & Ballou, 1988).
Percent due to recessive alleles	50%	Default based on studies of a limited number of species.
EV correlation between reproduction and survival	None	Not thought to be correlated in captivity.
Breeding system	Monogamous	Reflects intended management in captivity.
Age of first offspring (females & females)	2	Both sexes. From Anoa data.
Maximum age of reproduction (females and males)	18 years	Anoa recorded as living to mid-thirties but this is rare. Precautionary approach taken to lifespan assumption.
Maximum lifespan	24	Anoa recorded as living to mid-thirties but this is rare. Precautionary approach taken to lifespan assumption.
Maximum number of birth events per year	1	As for Anoa
Maximum number of offspring per event	1	As for Anoa (99.17% = 1 offspring; 0.83% = 2 offspring)
Sex-ratio at birth in % males*	50%	Based on Anoa data there is no reason to assume a value other than 50%. See note below*.
% adult females breeding (S.D)	35% (5%)	1980-2016: average proportion of females breeding each year for Europe & NA = 36.2, mode=30% with high associated variability. Likely to reflect management

VORTEX Parameter	Baseline Model Value	Rationale
		rather than potential, however, Saola expected to be challenging so 35% retained as a precautionary value.
Distribution of offspring number:		
1 offspring	100%	From Anoa data.
Female & Male mortality rates:		S.D. in mortality due to EV set to 20% of mean in each age-class
Age 0 to 1	25%	Informed by Anoa data.
Age 1 to 9	5%	Informed by Anoa data.
Age 10 to 18	10%	Informed by Anoa data.
After age 18 yrs	50%	In Anoa, annual mortality increases considerably after 19 years (males) and 21 years (females) though samples are small. This increase starts at 18 for Saola, which have been assigned a shorter lifespan.
% Males in breeding pool	100%	It is assumed all males can breed and will have the opportunity to do so.
Initial population size	4 adults	Only a limited number of Saola are expected to be captured from the wild.
Carrying capacity	50	Carrying capacity is set to 50 individuals for testing and verification.

***Note on sex-ratio at birth**. From the studbook (Nortzold & Alaze, 2020), 761 Anoa births showed a sex-ratio of 342 males to 366 females (53 young unassigned to either sex). A Chi-squared test returns a non-significant p-value of 0.367 so the hypothesis of a balanced sex-ratio cannot be rejected.

****Note on reproductive senescence**: in the Baseline Model (i.e. where all adults are retained until natural attrition) growth will be depressed by the accumulation of senescent adults. This constraint is removed in later management scenarios where non-breeders are excluded from the population.

With the model values described in Table 2., deterministic projections (i.e., without stochastic influences on reproduction and mortality rates) show a population that grows at an annual rate of 4% (λ =1.04). Generation time (for both sexes) is approximately 8 years. Stable age structure for this modelled population is illustrated in Figure 3 and shows the effect of the sex-differentiated increase in mortality in the older age-classes. Note that this age-structure (and the age-specific life expectancy that it suggests) may be optimistic and along with it the generation time of 8 years.

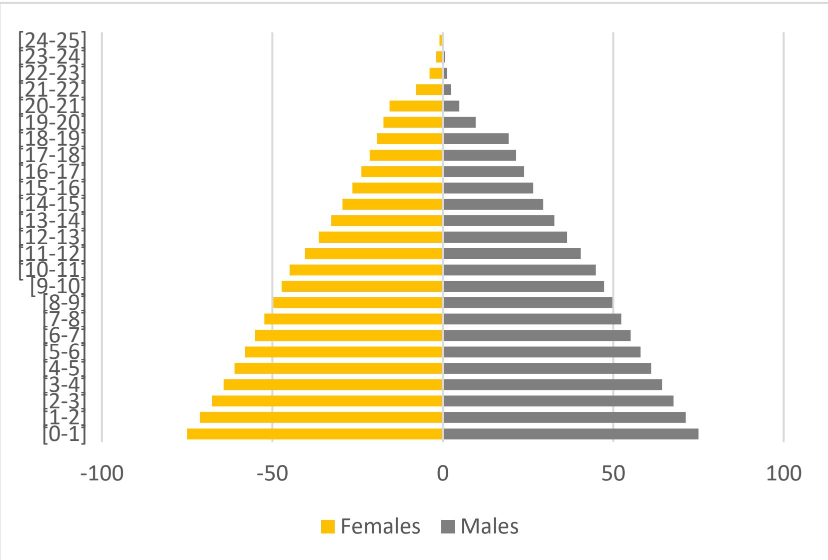
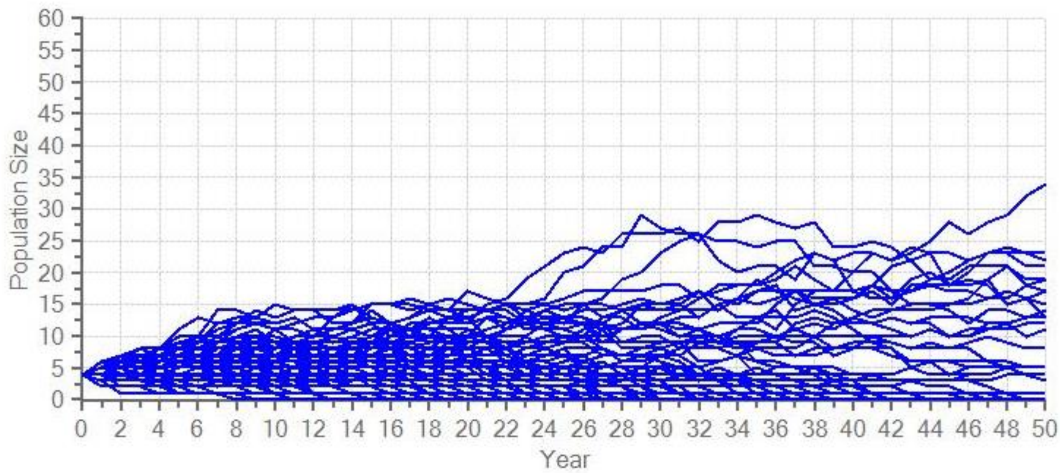


Figure 3. Age-pyramid portraying a stable-age structure for Saola, calculated using the input parameters provided. Numbers of males and females are shown on the X-axis; age-classes are shown in square brackets.

With stochastic elements included, instantaneous growth rate is only slightly positive (r=0.0016 ± 0.16) and the risk of extinction over the 50-year period is high (P(Ex)=0.81 or 81%). Among the populations that survive, numbers reach N=13.7 individuals on average but with much variation (SD= 10.99) and Gene Diversity at 50 years sits at 56%, well below internationally recommended thresholds of 90 – 95%. The carrying capacity of 50 individuals is almost never reached. See Figure 4.

Figure 4. Changes in population size over time in 100 iterations of the baseline model.



Tables 3a-b. Summary of deterministic and stochastic qualities of the Saola Baseline Model.

3a. Deterministic rates	
Lambda (λ)	1.04
Generational growth (Ro)	1.36
Generation time (T)	7.96

3b. Stochastic rates	
Instantaneous growth rate (r)	0.0016 ± 0.16
Gene Diversity (GD) at 50 yrs	56 ± 17%
Extinction Risk (PE)	81.00
N (All)	2.84 ± 7.33

Sensitivity Testing

Each parameter in turn was varied across a plausible range of values to explore which of them have the greatest impact on model performance (see Table 4). Those with most influence should be targets for further information gathering (where they are the subject of uncertainty) or for discussions about management intervention where this is feasible.

More influential parameters. Across the ranges of values tested, initial population size, juvenile mortality rates, and the percentage of females breeding annually, were most influential. Reducing juvenile mortality from 25 to 10% increased growth rate from r=0.0016 to 0.064. Increasing the proportion of breeding females from 35 to 50% increased growth rate to r=0.04. Both parameters also affected population extinction risk (See Tables 6a-k for the results of all sensitivity tests).

Less influential parameters. Age at first breeding and adult mortality rates were less influential factors across the range of values tested.

Parameters (biology)	Tested values
Age 1st offspring (f)	5; 4; 3; **2**; 1
Age 1st offspring (m)	5; 4; 3; **2**; 1
Maximum lifespan	16; 17; **18**; 19; 20
% Breeding Females	20; 25; 30; **35**; 40; 45; 50
Mort. Rates % [0;1]	40; 35; 30; **25**; 20; 15; 10
Mort. Rates % [2;10]	8; 7; 6; **5**; 4; 3; 2
Mort. Rates % [10;18[	16; 14; 12; **10**; 8; 6; 4
Sex-Ratio (% male)	56; 54; 52; **50**; 48; 46; 44

Table 4. Values used to test the sensitivity of the Saola Captive Baseline Model to uncertainty or variation in individual parameters. Baseline values are in red.

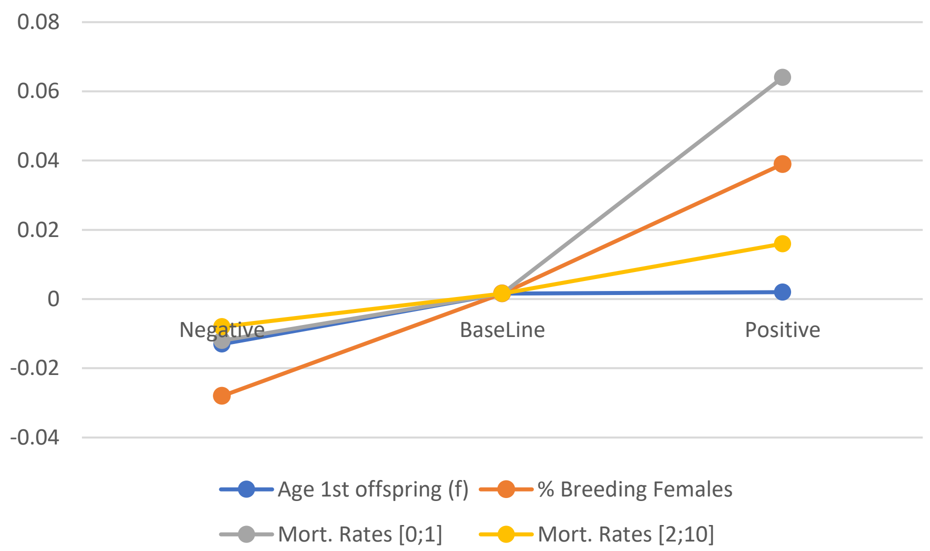


Figure 5. Summary of the sensitivity testing for the most influential parameters.

Tables 5a-k. Results of all sensitivity tests carried out for Saola (showing stochastic growth rate (r), 50-year extinction risk (P(Ex)), mean population size across iterations at 50 years, excluding those that went extinct (N-Ext), mean population size at 50 years for all populations including those that went extinct (N-All), and gene diversity at 50 years (GD). Baseline value is highlighted in **RED.**

6a) Age 1st offspring (f)	5	4	3	**2**	1
r	-0.013	-0.01	0.001	0.0016	0.01
P(Ex)	0.95	0.93	0.85	0.82	0.73
N-Ext	6.76	7.27	10.58	13.78	21.05
N-All	0.38	0.62	1.6	2.65	5
GD	0.43	0.48	0.54	0.54	0.56

6b) Age 1st offspring (m)	5	4	3	**2**	1
r	-0.002	-0.002	-0.001	0.0016	0.001
P(Ex)	0.86	0.87	0.84	0.82	0.82
N-Ext	12.06	12.25	12.84	13.78	13.05
N-All	1.78	1.69	2.16	2.65	2.42
GD	0.55	0.53	0.54	0.54	0.51

6c) Maximum Lifespan (f)	16	17	**18**	19	20
r	-0.001	0.001	0.0016	0.002	0.004
P(Ex)	0.83	0.84	0.82	0.81	0.79
N-Ext	11.48	15.34	13.78	14.09	15.55
N-All	5.63	2.57	2.65	2.78	3.42
GD	0.51	0.56	0.54	0.55	0.54

6d) Maximum Lifespan (m)	16	17	**18**	19	20
r	0	0	0.0016	0.003	0.003
P(Ex)	0.83	0.82	0.82	0.79	0.78
N-Ext	12.97	14.2	13.78	15.6	13.64
N-All	2.29	2.61	2.65	3.37	3.16
GD	0.52	0.51	0.54	0.56	0.55

6e) % Breeding female	20%	25%	30%	**35%**	40%	45%	50%
r	-0.028	-0.018	-0.008	0.0016	0.014	0.024	0.039
P(Ex)	0.99	0.97	0.91	0.82	0.67	0.54	0.38
N-Ext	3.8	5.26	8.3	13.78	22.24	28.78	35.59
N-All	0.05	0.2	0.76	2.65	7.5	13.23	22.02
GD	0.44	0.48	0.51	0.54	0.59	0.58	0.63

6f) Mort. Rates [0;1]	40%	35%	30%	**25%**	20%	15%	10%
r	-0.012	-0.008	-0.004	0.0016	0.0049	0.012	0.064
P(Ex)	0.94	0.89	0.87	0.82	0.75	0.68	0.58
N-Ext	7.81	7.45	11.31	13.78	15.61	21.13	25.1
N-All	0.52	0.84	1.61	2.65	4.01	6.76	10.67
GD	0.51	0.47	0.54	0.54	0.54	0.58	0.58

6g) Mort. Rates [3;10]	8%	7%	6%	**5%**	4%	3%	2%
r	-0.008	-0.006	-0.004	0.0016	0.006	0.009	0.016
P(Ex)	0.92	0.9	0.87	0.82	0.74	0.71	0.57
N-Ext	9.79	10.33	11.21	13.78	15.95	18.63	20.38
N	0.87	1.1	1.5	2.65	4.18	5.41	8.82
GD	0.49	0.49	0.51	0.54	0.56	0.58	0.59

6h) Mort. Rates [10;+]	16%	14%	12%	**10%**	8%	6%	4%
r	-0.005	-0.004	0	0.0016	0.004	0.006	0.007
P(Ex)	0.89	0.88	0.82	0.82	0.77	0.76	0.72
N-Ext	11.63	12.75	12.83	13.78	14.54	15.84	15.32
N-All	1.41	1.66	2.48	2.65	3.47	3.95	4.42
GD	0.54	0.54	0.54	0.54	0.54	0.54	0.55

6i) Sex-Ratio (m)	54%	52%	**50%**	48%	46%
r	-0.0018	-0.0011	0.0016	0.002	0.005
P(Ex)	0.84	0.83	0.82	0.81	0.76
N-Ext	10.8	13.19	13.78	14.43	15.47
N-All	1.8	2.29	2.65	2.89	3.76
GD	0.53	0.56	0.54	0.55	0.56

6j) Ni	2	**4**	6	8	10	12	14
r	0.024	0.0016	0.002	0.004	0.007	0.011	0.014
P(Ex)	0.96	0.82	0.59	0.43	0.31	0.19	0.12
N-Ext	11.3	13.78	19.32	23.3	27.53	30	33.7
N	0.46	2.65	8.1	13.35	19.19	24	29.9
GD	0.43	0.54	0.62	0.68	0.72	0.75	0.78

6k) K (Ni=10)	20	30	40	**50**	60	70	80
r	0.005	0.007	0.007	0.008	0.009	0.009	0.01
P(Ex)	0.31	0.26	0.29	0.31	0.26	0.27	0.25
Next	13.19	19.23	23.59	27.59	29.46	31.6	32
N-All	9.33	14.36	16.95	19.22	21.81	23.15	23.88
GD	0.67	0.71	0.71	18.41	0.73	0.72	0.72

Scenario Testing

No wild models were built for Saola. Based on the estimates and analyses to date it was agreed that the chance of successful establishment of a captive population for this species is so remote that estimating wild parameters, and calculating potential harvest capability for releases, would not be worthwhile at this point. This area of work can be returned to should the situation change.

Further modelling work was directed at exploring the potential impact on captive model performance of the following:

1) Gradually improving husbandry in ways that:
    - increase the percentage of females breeding annually from 35-50%;
    - reduce mortality from 25–15% in juveniles and from 10-5% in adults aged 10-18 years.
2) Good or bad luck with respect to the number and sex-ratio of any founders captured.
3) The severity of inbreeding depression.

Scenario 1. Improving Husbandry: Female Reproduction

- A founder group of four adult Saola is captured in Year 1.
- The percentage of females that breed each year increases from 35 to 50% over the first five years of the program.
- The population is allowed to grow to 50 individuals.
- Non-reproductive animals remain in the population.

Figure 6. shows the results for Scenario 1. As illustrated, with the gradual increase in the percentage of females breeding each year, extinction risk reduces considerably but remains high (P(Ex)=47%) and population size, or N-Extant at 50 years, is highly variable, at 32.75 ± 17.3. Gene diversity after 50 years is low (GD=61%).

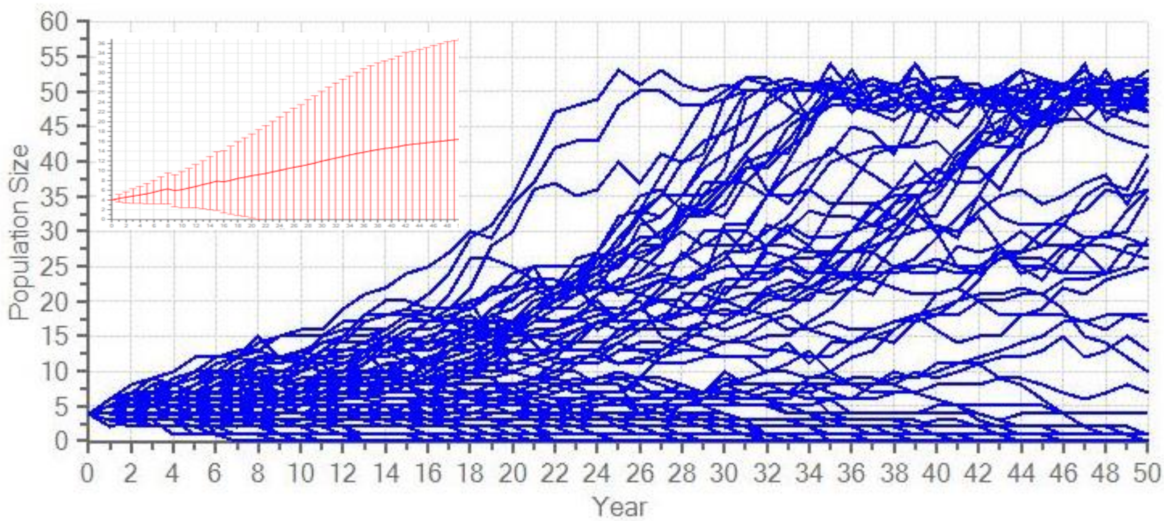


Figure 6. Scenario 1 results showing 100 iterations, most ending in extinction (47%) and few reaching carrying capacity (~10%).

Despite these poor results the Scenario 1 model performs considerably better than the Baseline Model. A comparison between the two is shown in Table 6. Growth is much improved (increasing from r=0.0016 to 0.031); Gene Diversity is up 6%; and Probability of Extinction is reduced from 81-47%.

Table 6. Stochastic qualities of the Saola *ex situ* Model under Scenario 1., compared to the Baseline.

Stochastic rates	Baseline Model	Scenario 1
Instantaneous growth rate (r)	0.0016 ± 0.16	0.031 ± 0.14
% Gene Diversity (GD) at 50 yrs	56 ± 17%	61 ± 0.16
Extinction Risk (PE)	0.81	0.47
N (Extant)	14.7 ± 11.5	32.7 ± 17.3
N (All)	2.8 ± 7.3	15.9 ± 20.2

Scenario 2. Improving Husbandry: Mortality

Three different versions of this scenario were run, each involving a staggered reduction in mortality over the first three years of the programme, with the age-classes affected varied as follows:

Between Year 1 and Year 3:

a. **Adults:** mortality drops from 10% to 5% in the 10-18-year age-classes.
b. **Juveniles:** mortality drops from 25% to 15% in the 0-1-year age-class.
c. **Adults & Juveniles:** mortality drops from 10% to 5% in the 10-18-year age-classes and from 25% to 15% in the 0-1-year age-class.

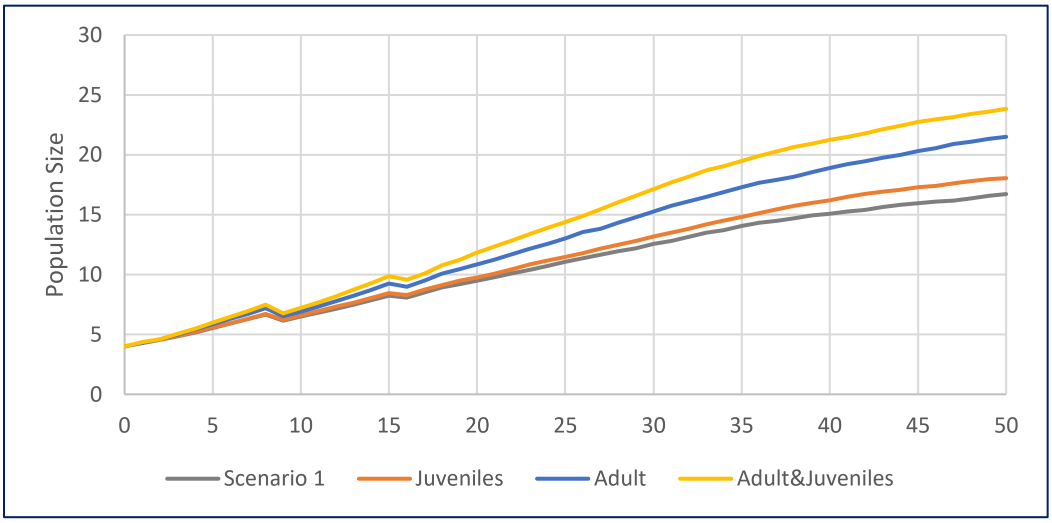


Figure 7. Comparison between Scenario 1 (female breeding rate improves) and Scenarios 2a, 2b and 2c (mortality rates improve).

Figure 7. compares the impact of increasing the percentage of females breeding annually (Scenario 1) with the impact of decreasing mortality rates. As can be seen, for the values modelled, reducing juvenile mortality performs slightly better than increasing female reproduction, reducing adult mortality performs better still, and reducing both juvenile and adult mortality is the best performing scenario. Extinction risk and gene diversity are similarly improved (see Table 7).

Table 7. Stochastic outputs for Scenario 1 and Scenarios 2a, 2b and 2c.

	r	N-ext	PE	GD
Sc 1 (Female reproduction)	0.031 (± 0.14)	32.75 (± 17.3)	0.492	0.6148 (± 0.16)
Sc 2a (Juveniles)	0.039 (± 0.13)	34.16 (± 16.8)	0.473	0.6126 (± 0.16)
Sc 2b (Adults)	0.034 (± 0.13)	36.13 (± 16.7)	0.407	0.6126 (± 0.16)
Sc 2c (Adults & Juveniles)	0.041 (± 0.13)	36.73 (± 16.2)	0.353	0.6232 (± 0.15)

Scenario 3. Severity of Inbreeding Depression

The population in Scenario 1. is initiated with four individuals and as a result gene diversity loss and levels of inbreeding after 50 years are high (population mean inbreeding at year 50: I=0.3647+/-0.0178). In VORTEX, the default setting (used here) allows inbreeding to affect individuals by increasing their risk of mortality in the first year, with a severity specified by the user. To illustrate the size of this effect in the Saola models, and the factors that influence it, two complementary scenarios were developed, based on Scenario 1:

- Scenario 3a: Inbreeding depression in VORTEX (i.e. the increased mortality applied to inbred juveniles) is switched off.
- Scenario 3b: inbreeding depression is switched on and one additional Saola is added from the wild, once every 5 years, for the first 20 years of the program.

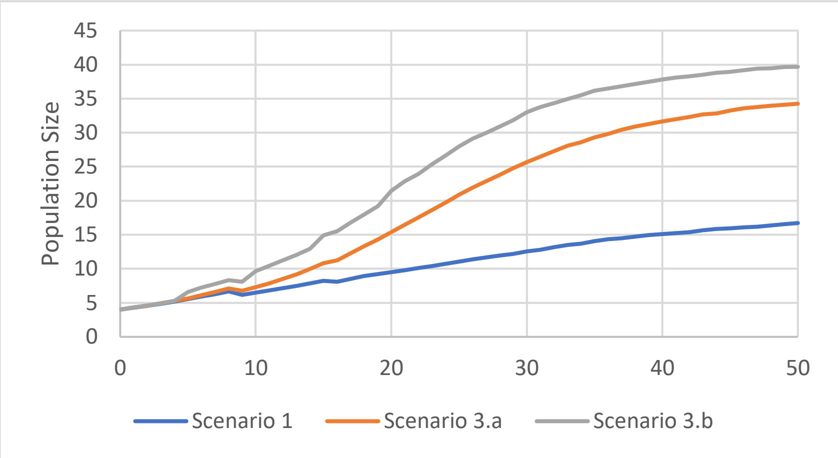


Figure 8. Comparison between Scenario 1. (with default inbreeding severity) and Scenarios 3a. (no inbreeding) and 3b. (inbreeding mitigated by the addition of one unrelated individual every five years, for the first twenty years).

For this population the impact of inbreeding is potentially considerable. Removing it completely (Scenario 3a.) allows the population to grow faster (r=0.071 ± 0.12 compared to r=0.031 ± 0.14 with it included) and towards larger numbers (N-Ext=32.75 ± 17.3 with inbreeding; N=47.31 ± 8.79 without it). It also reduces the probability of extinction (P(Ex)=0.27 without; P(Ex)=0.49 with).

Supplementing with one wild Saola every five years (Scenario 3b.), delivers results for growth and extinction risk similar to those of removing inbreeding effects from the model (r=0.066 ± 0.11; N-Ext=45.65 ± 0.13; P(Ex)=0.13) and also results in higher levels of gene diversity (GD at 50 years=77.5 ± 0.09 versus GD=0.62 ± 0.15). Altogether, the addition of a few individuals helps to reduce the impact of both stochastic events and inbreeding depression, leading the population to a more acceptable extinction risk (13%).

Note that suppressing the lethal effects of inbreeding depression through additional supplementation from the wild is unlikely to be possible.

Scenario 4: Initial Population Size and Sex-ratio

To estimate the influence of the initial population size and sex-ratio, we developed a fourth scenario in which we allowed initial population size (Ni) to vary between 2 and 6 animals. For each initial population size, we tested the influence of every possible sex-ratio (except for single-sex options). All other model parameters follow those for Scenario 1. The results are summarised in Table 8.

Table 8. Stochastic outputs for Scenario 4. Orange: scenarios with extinction probabilities ranging from 0.5 - 1; Yellow: scenarios with P(Ex) ranging from 0.3 - 0.5; Green: scenarios with P(Ex) ranging from 0.0 - 0.3.

Ni	Males	Females	Stoch-r	PE	N-all	GeneDiv
2	1	1	0.037 ± 0.16	0.86	3.3 ± 10.11	0.47 ± 0.17
3	1	2	0.03 ± 0.14	0.62	11.6 ± 18.1	0.56 ± 0.17
	2	1	0.025 ± 0.15	0.72	6.99 ± 14.3	0.52 ± 0.18
4	1	3	0.035 ± 0.12	0.42	19.36 ± 20.94	0.61 ± 0.16
	2	2	0.035 ± 0.13	0.48	18.69 ± 21.44	0.62 ± 0.16
	3	1	0.018 ± 0.15	0.72	8.27 ± 15.88	0.55 ± 0.19
5	1	4	0.032 ± 0.12	0.42	20.95 ± 21.62	0.63 ± 0.15
	2	3	0.039 ± 0.12	0.29	37.34 ± 31.78	0.67 ± 0.14
	3	2	0.034 ± 0.12	0.37	23.29 ± 21.95	0.65 ± 0.14
	4	1	0.014 ± 0.14	0.69	8.91 ± 16.57	0.58 ± 0.17
6	1	5	0.033 ± 0.12	0.36	23.83 ± 21.91	0.65 ± 0.15
	2	4	0.045 ± 0.11	0.19	34.12 ± 20.53	0.7 ± 0.14
	3	3	0.041 ± 0.11	0.24	31.27 ± 21.43	0.71 ± 0.13
	4	2	0.03 ± 0.12	0.35	24.42 ± 22.18	0.66 ± 0.15
	5	1	0.009 ± 0.14	0.69	9.47 ± 17	0.6 ± 0.16

Increasing initial population size from Ni=2 to Ni=6 (with an even sex-ratio) reduced 50-year extinction risk from P(Ex)=0.86 to P(Ex)=0.24 and increased 50-year gene diversity retention from GD=0.47 to GD=0.71; mean stochastic growth rate increased from r=0.037 to r=0.041 (See Table 9).

A balanced sex-ratio of initial breeders, or one slightly in favour of females, increases the chance of the population growing and surviving. A starting population with two few males, or with too many, has the opposite effect.

Summary

From the information and advice available for this analysis the following tentative conclusions can be drawn:

- A founder base of 2 – 6 Saola confers a small chance of successfully establishing a captive population.
- Over the timeframe considered (50 years), a population built from that founder-base would be unlikely to grow large enough to enable a harvest for release.
- A run of good luck could enhance prospects (e.g. capturing a roughly even sex-ratio of founders or one slightly skewed towards females; or finding that Saola are less affected by inbreeding accumulation than other, similar species).
- Should founders be successfully acquired, successfully reducing captive mortality rates and maximising reproductive rates within the first few years could have a considerable positive impact on longer-term viability prospects, though they would remain tenuous.
- Excellence in husbandry from the outset, and facilities that support this, are critical to giving this species the best chance of survival.

MUNTJAC

Introduction

This analysis was initially directed towards the Large-antlered Muntjac (*Muntiacus vuquangensis*). It was subsequently agreed that it could also be used to inform planning for three species of Dark Muntjac (*Muntiacus rooseveltorum, Muntiacus truongsonensis and Muntiacus puhoatensis*).

Muntiacus vuquangensis. This is the largest muntjac species. It is found in areas of Vietnam, Lao PDR and Cambodia and was not known to Western science until 1994. It is categorised as Critically Endangered (IUCN 2016) based on an estimated decline of 90% over the previous 15-25 years. There are now very few sites holding significant populations. Currently, the species is not known to be held in captivity anywhere. Thirty-eight individuals were captured during inundation of the Nakai Reservoir in Lao PDR, studied, and then successfully relocated into an adjacent Protected Area (Stone 2009), indicating some resilience to intensive management.

Muntiacus rooseveltorum, M. truongsonensis and M. puhoatensis. These species are part of a currently unresolved species complex. All are categorised as Data Deficient (IUCN 2016) due to taxonomic uncertainties that prevent clarification of species limits and therefore of conservation status and threats. All are expected to be threatened by forest loss to agriculture and indiscriminate hunting. Tolerances to the latter may vary among taxa but this is not known.

The conservation plan for all these species involves capturing founders from the wild and growing a population in captive facilities in Vietnam, to provide a source of individuals for release to protected wild sites. Though these species have not been managed in captivity previously, other *Muntiacus* species have thrived there, as well as in the wild outside their range as introduced populations. This, and the likelihood that a good founder base might be achievable for at least some of these species, provided some justification for optimism among PVA contributors.

Summary of Findings to Date

For a successful captive model	Findings	Notes
How many founders?	20+	For 50-year outcomes
How large a population?	50+	For 50-year outcomes
What rates of breeding & survival?	As per Baseline Model	
What rate of supplementation?	None needed	Assuming early husbandry success
What level of genetic management?	Intensive	Assumes at least random breeding but pairwise by mean kinship is better.
How long before releases can begin?	4-8 years	With sufficient founders and early husbandry success.
What size, composition & frequency of release cohorts could be possible?	TBC	

For a successful wild model	Findings	Notes
What is the minimum viable population size?	50 (50 yrs)	
How many animals should be in a release cohort?	20+	Further work on this awaits developments in the wider Muntjac program.
Of what age and sex?	TBC	
What release frequency?	TBC	
How many years to re-establishment?	TBC	
How much ongoing supplementation will be needed and from where?	TBC	

Meta-population question	
With plausible inputs can we create a successful scenario?	Yes, depending on the level of snaring intensity assumed.

Captive Baseline Model

There are no captive data available for any of the target Muntjac taxa. Reeve's Muntjac (*Muntiacus reevesi*), for which there are both captive and wild population data, was used as an analogue. Demographic and reproductive values were drawn from the AZA studbook for the species with assistance from John Andrews. Values were modified where necessary to fit the expected conditions and management regime proposed for a Vietnam population. The values applied are detailed in Table 9.

Deterministic	λ	1.22
	Ro	2.61
	Tf	4.92
	Tm	5.24
	r	0.19
Stochastic	r	0.148±0.12
	N	98.6 ± 5.35
	GD at 50yrs	87.8 ± 0.3%
	PE at 50 yrs	0

Table 9. Deterministic and stochastic performance indicators for the Muntjac Captive Baseline Model.

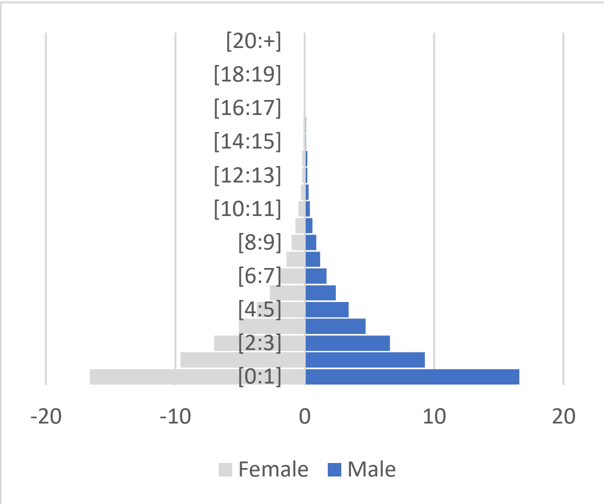


Figure 9. Stable Age-structure for the Captive Baseline Model for Muntjac.

With the model values described in Table 10., deterministic projections (i.e., without stochastic influences on reproduction and mortality rates) show a population that grows at an annual rate of 21% (λ =1.21). Generation time (T) (for both sexes) is close to 5 years. Stable age structure for this modelled population is illustrated in Figure 9. **Note that this age-structure (and the age-specific life**

expectancy that it suggests) may be optimistic and along with it the generation time of 5 years (i.e. these may be shorter).

With stochastic elements included, instantaneous growth rate is still positive (r=0. 15 ± 0.12) and the expected risk of extinction over the 50-year period is zero (P(Ex)=0.00). Among the populations that survive, numbers almost always reach the carrying capacity fixed at 50 individuals (98.6 ± 5.35). Gene Diversity at 50 years sits at 87.8% (± 0.03), which is below internationally recommended thresholds of 90 – 95% (note though that this is not necessarily a problem for the captive programme as long as within that timeframe releases have been successful at establishing larger, genetically diverse wild populations).

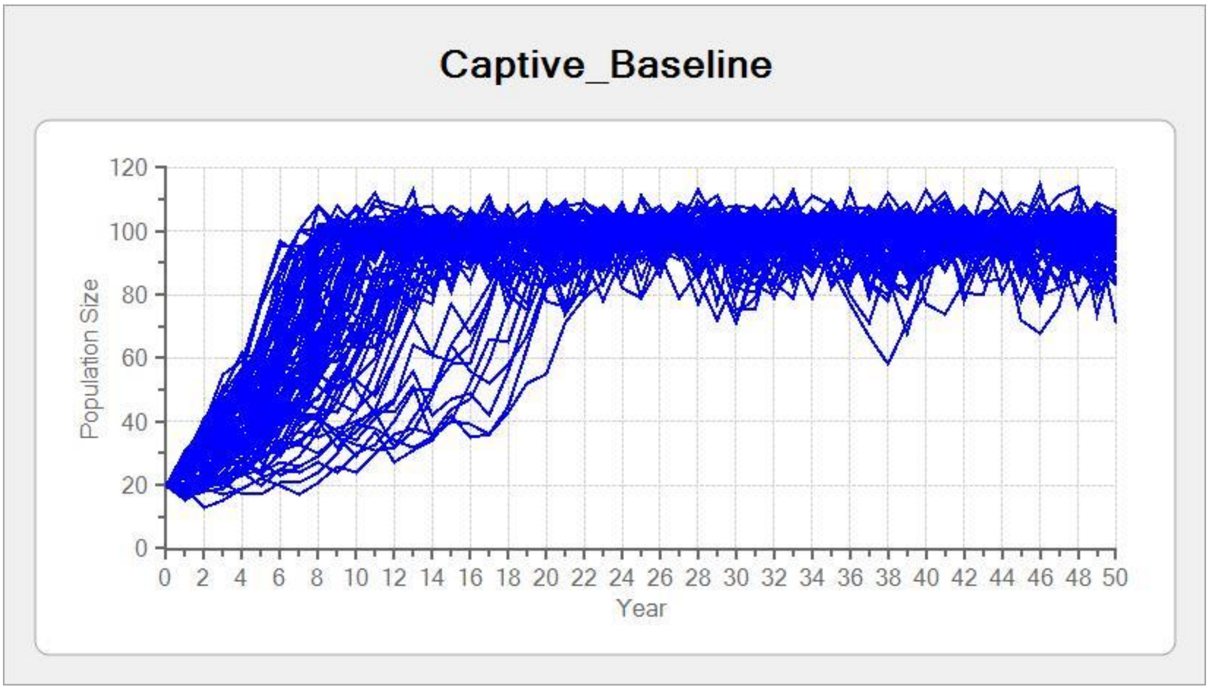


Figure 10. VORTEX visualisation of the population trajectories of 100 simulations of the Captive Baseline Model for Muntjac

Table 10. Parameters used in Captive and Wild Baseline Models for Muntjac species.

Vortex Parameters	**Captive (VIET)**	**Wild**	**Details**
Period modelled	50 years	50 years	To allow investigation of long-term prospects
Inbreeding depression severity	3.14 Lethal Equivalents	6.29 Lethal Equivalents	Default based on captive & wild studies of other species
Percent due to recessive alleles	50%	50%	Default based on studies of a limited number of species
EV correlation between reproduction and survival	0.0	0.5	Not known. Factors affecting the two not expected to be coupled *ex situ*.
Breeding system	Monogamous	Polygynous	Difference represents proposed management approach *ex situ*
Age of first offspring	2 years	2 years	Estimated from Reeve's Muntjac data (captive). Suggests breeding at one year-old is possible but rare.
Maximum age of reproduction	F=12 yrs; M=18yrs	12 years	Females: captive life-table data show a drop in risk of breeding starting age 8 with sudden 50% reduction at age 13-14. No breeding recorded after age 17. Drop-off starts at 12yrs for males, no breeding after 20 yrs. May reflect mgmnt but not known. No wild data.
Maximum lifespan	20 years	12 years	Only 1% of captive animals reach 20yrs. Records of animals living much longer may be errors.
Maximum number of broods per year	2	2	UK Mammal Society (for Reeve's Muntjac) reports gestation period of 210 days, post-partum oestrus and year-round breeding, so females can have 3 calves every 2 years. Distribution of broods is used to indicate mean of 1.5.
Maximum number of progeny per brood	1	1	From captive and wild data for Reeve's. Twins are very rare (UK Mammal Soc.)
Sex-ratio at birth in % males	50%	50%	No data to support a sex-ratio skew at birth
% adult females breeding (S.D)	90% (5%)	90% (5%)	Not known. In captive scenarios a hypothesised increase from 30-90% in years 1-3 (= improved husbandry). Wild begins at 90%.
Distribution of brood sizes (%):			
1, 2	50%, 50%	50%, 50%	Distribution of broods used to indicate mean of 1.5 calves per year for breeding females.
Female mortality rates (%)			**SD in mortality due to EV set to 10% of mean in each age-class**
Age 0 to 1	26%	26%	From life-table data for captive Reeve's Muntjac,
Age 1+	7%	20%	% increased to reflect increased pressures in the wild (estimate only - no data available).
Age 2+	7+(3*(A>6)+(9*(A>11)+(31*(A>17)	7+(3*(A>6)+(9*(A>50)	**Captive:** Age2-6=7%; Age 7-11=10%; Age 12-17=19%; Age 18+=50%. **Wild:** Age 2-6=7%; Age 7-9=10%; Age 10+=50%
Male mortality rates (%)			**SD in mortality due to EV set to 10% of mean in each age-class**
Age 0 to 1	28%	28%	From life-table data for captive Reeve's Muntjac, adapted in the wild model for shorter lifespan.
Age 1+	9%	20%	% increased to reflect increased pressures in the wild (estimate only - no data available).
Age 2+	9+(17*(A>12)+(4*(A>15)+(20*(A>17)	9+(41*(A>10)	**Captive:** Age 2-12=9%; Age 13-15=26%; Age >15=50%; **Wild:** Age 2-10=9%; Age 11+=50%
% Males in breeding pool	100%	50%	Species is territorial – assume competition favours some males more than others in the wild, but not necessarily in captivity.
Initial population size	20 (10M;10F)	20 ADULTS (10M;10F)	In harvest models the captive population is set to 25.25 adults, young are released, adults are retained and replaced as needed (with young).
Carrying capacity	100	100	Wild K is set to 100 for initial testing, captive K is set to 100. This includes both adults and young.
Catastrophes	Freq. 25%; Survival: 0.8	Freq. 3.5%; Survival: 50%	Captivity: human-mediated trauma once every 3-5 years resulting in 20% loss of population (captivity only). Wild – Reed et al. generic catastrophe.

Sensitivity Testing

Each parameter in turn was varied, across a plausible range of values, to explore which have the greatest impact on model performance. Those with most influence should be targets for further information gathering (where they are the subject of uncertainty) or for discussions about management intervention where this is feasible.

More influential parameters. Age at first offspring, percentage of females breeding each year and number of "broods", mortality rates age 0-12 years.

Less influential parameters. Lifespan, age at last reproduction, mortality in age-classes 12-years and older, sex-ratio bias.

Table 11. Values used to test the sensitivity of the Muntjac Captive Baseline Model to uncertainty or variation in individual parameters. Baseline values are in red.

Parameters (biology)	Tested values	Associated growth rate
Age 1st offspring (f)	4, 3, **2**, 1	0.06, 0.11, **0.15**, 0.17
Age 1st offspring (m)	4, 3, **2**, 1	0.07, 0.11, **0.15**, 0.16
Age at last reproduction (f)	8, 10, **12**, 14, 16	0.13, 0.14, **0.15**, 0.15, 0.15
Age at last reproduction (m)	12, 14, 16, **18**, 20	0.14, 0.15, 0.15, **0.15**, 0.15
Maximum lifespan	16, 18, **20**, 22, 24	0.15, 0.15, **0.15**, 0.15, 0.15
% Breeding Females	60, 70, 80, **90**, 100	0.07, 0.11, 0.13, **0.15**, 0.15
Brood distribution	[50;25;25]; [25;50;25]; [25;25;50]; **[0;50;50]**; [0;25;75]	-0.02, 0.06, 0.11, **0.15**, 0.16
Mort. Rates % [0;1]	36;31;**26**;21;16	0.03, 0.09, **0.15**, 0.19, 0.22
Mort. Rates % [2;12]	17;12;**7**;2;0	0.01, 0.07, **0.15**, 0.17, 0.20
Mort. Rates % [12;+[	29;24;**19**;14;9	0.15, 0.15, **0.15**, 0.15, 0.15
Sex-Ratio (% male)	60;55;**50**;45;40	0.11, 0.14, **0.15**, 0.14, 0.12

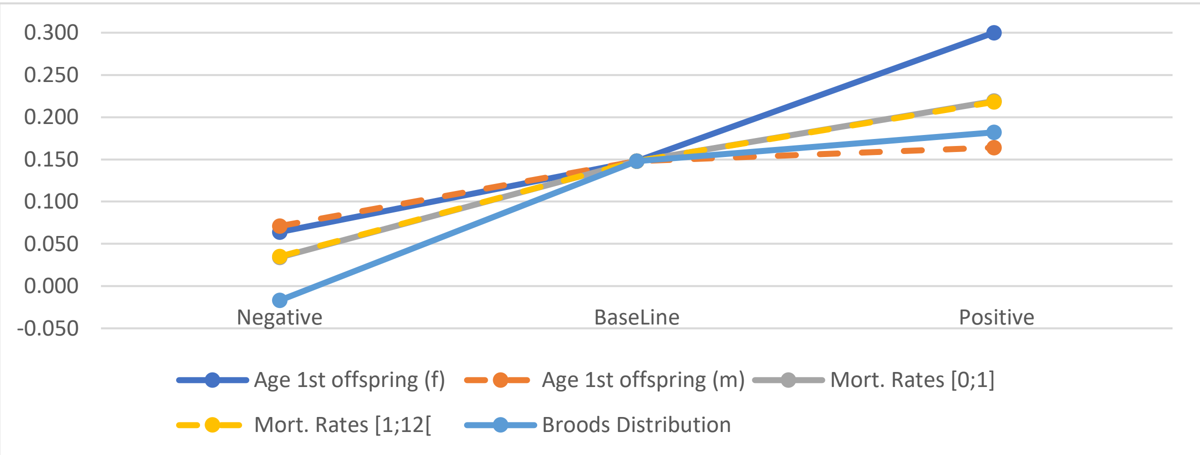


Figure 11. Graph illustrating the relative impact of a subset of parameter uncertainty on model performance.

Wild Baseline Model

There are no wild population data for these species. Therefore, captive data were modified to create a Wild Baseline Model (see Table 13). In summary: the captive trauma and husbandry learning period was removed; inbreeding impact was increased (to the VORTEX wild default); longevity was reduced from 20 to 12 years with no period of reproductive senescence; the species was switched from monogamous to polygynous; male contributors to the breeding pool were reduced from 100% to 50%; > 10 year-old males were assigned increased mortality; and a generic catastrophe was introduced (14% chance per generation of a 50% loss of individuals based on Reed et al. 2003).

Table 12. A comparison of Captive and Wild Baseline Model outputs.

Performance indicator (50 yrs)	Captive	Wild
Growth (Stoc-r)	0.149 (SD=0.118)	0.133 (SD=0.159)
P(Ex) (Extinction)	0.00	0.01
Mean population size	98 (K=100)	93 (K=100)
GD at 50 years	87% (20founders)	85% (20 founders)
Time to capacity	6-8 years (K=100)	10-12 years (K=100)

As shown in Table 12. and in Figures 12 and 13, performance of the two models is similar. In general, both grow strongly towards carrying capacity with all iterations surviving. On average, population size reaches available capacity in 5-10 years and remains at around that size over the period. Due to small starting size and carrying capacity, and the short generation time (approx. 5 years), gene diversity in both is below recommended levels by 50 years. Due to shorter lifespan, higher age-specific mortality rates and the less frequent but more severe catastrophes, the wild model shows higher variability and occasionally goes extinct (P(Ex)=0.01 or 1%).

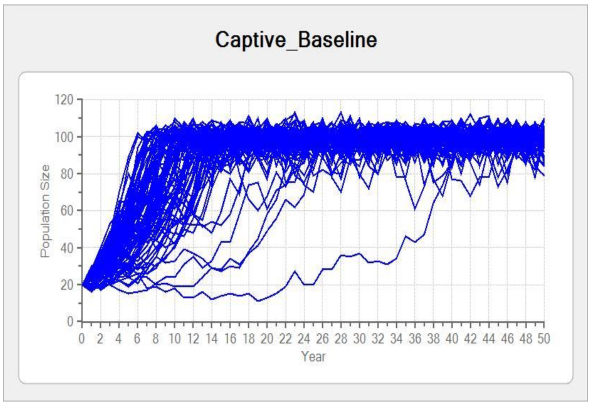


Figure 12. VORTEX visualisation of the population trajectories of 100 simulations of the Captive Baseline Model for Muntjac (Ni=20; K=100)

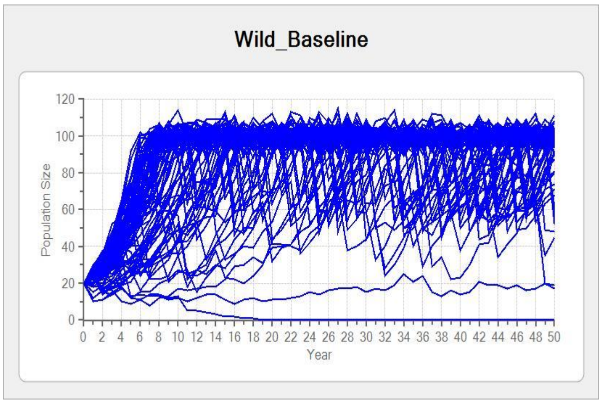


Figure 13. VORTEX visualisation of the population trajectories of 100 simulations of the Wild Baseline Model for Muntjac (Ni=20; K=100)

Scenario Testing

Estimated site-specific carrying capacities range from 70 – 5850 individuals for these species, based on estimated densities in preferred habitat, and on the estimated amount of preferred habitat at each of the potentially suitable sites. Estimated snaring rates range from 10-20% offtake per year at the most intensively protected sites, to 50-90% offtake per year at the least intensively protected sites (all estimates provided by A. Tilker).

A series of models were run aimed at answering the following questions (for a 50-year timeframe):

- What is the minimum viable population size (MVP) for a wild population of this species (as currently modelled) in absence of snaring?[1]
- What level of snaring (offtake) can populations of different size tolerate?
- How many Muntjac would need to be released each year, and for how many years, to successfully establish a population able to support a non-zero level of offtake of 5%, 10% etc?

What is the Minimum Viable Population size?

Table 13. illustrates the effect on 50-year extinction risk of varying carrying capacity from K=10 to 100, and initial population size from Ni=5-50. As expected, the risk of extinction drops with larger initial population size and larger carrying capacities. The definition of viability in this case is met by populations beginning with a minimum of Ni=20 and able to grow to at least K=50, or with a minimum starting size of Ni=40 and a carrying capacity of at least that. Note that even in the best-case scenarios shown here (P(Ex)=0), the genetic diversity maintained in the population after 50 years is 88-89%, which is below international recommended thresholds for captive populations.

Note that these are likely to be optimistic MVP estimates as they cover only a short period (50-year) and portray a wild population without snaring pressure. Beyond the 50-year period, populations of such small size and with lowered gene diversity could be expected to suffer declines from inbreeding effects.

Table 13. The effect on extinction risk of varying carrying capacity from K=10-100, and initial population size from Ni=5-50. (Green shading; P(Ex)=0.00-0.01; Yellow; P(Ex)=0.00-0.10; Pale Orange; 0.10-0.20; Dark Orange; P(Ex) >0.20)

	P(Ex)	K						
Ni		10	20	30	40	50	75	100
	5	0.9	0.5	0.36	0.38	0.32	0.31	0.36
	10	0.86	0.29	0.10	0.08	0.06	0.05	0.04
	20	-	0.26	0.05	0.02	0.01	0.00	0.00
	30	-	-	0.05	0.02	0.00	0.00	0.00
	40	-	-	-	0.01	0.00	0.00	0.00
	50	-	-	-	-	0.00	0.00	0.00

[1] Where MVP is defined as 1% extinction risk or less over (in this case) 50 years.

What level of snaring could be tolerated without supplementation?

Models were run to consider the extent to which increasing initial population size and carrying capacity can overcome snaring pressure in absence of ongoing population supplementation. The results are shown in Figure 14. and in Table 14.

As illustrated, populations that start and remain at N=25 cannot withstand any snaring pressure whereas those of N=50-75 can sustain a snaring intensity of 5%. Even populations of N=200 could not sustain a snaring intensity of 20%.

Figure 14. The relationship between population size, snaring intensity and extinction risk. (Green P(Ex)=0.00-0.10; Yellow P(Ex)=0.1-0.20; Pale Orange P(Ex)=0.20-0.50; Orange P(Ex)=0.05-0.8; Dark Orange P(Ex) >0.80)

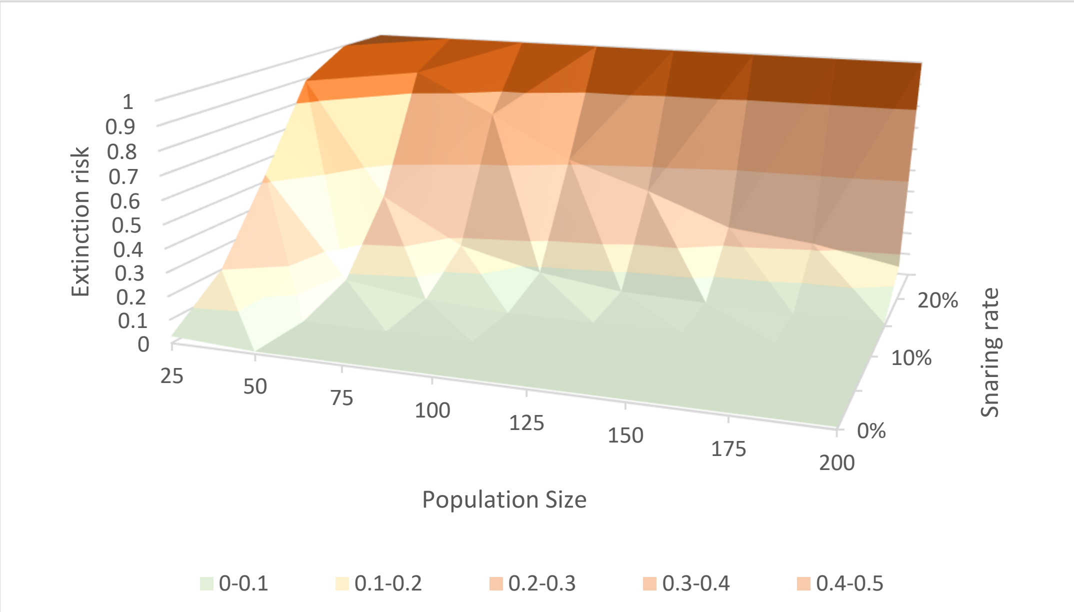


Table 14. Shows Figure 14 in table form, illustrating the effect on extinction risk of varying population size from 25-100 and snaring intensity from 0-25%, without supplementation. (Green P(Ex)=0.00-0.01; Yellow P(Ex)=0.01-0.20; Pale Orange P(Ex)=0.20-0.50; Orange P(Ex)=0.05-0.8; Dark Orange P(Ex) >0.80))

P(Ex)		Ni=K							
		25	50	75	100	125	150	175	200
Snaring intensity	0%	0.08	0.01	0	0	0	0	0	0
	5%	0.39	0.04	0	0	0	0	0	0
	10%	0.78	0.25	0.07	0.03	0	0	0	0
	15%	0.99	0.76	0.65	0.63	0.2	0.10	0.08	0.08
	20%	1	1	0.96	0.95	0.88	0.78	0.71	0.71
	25%	1	1	1	1	1	1	0.99	0.99

What level of snaring could be tolerated with ongoing supplementation?

Capacities of K=25-200 are at the low end of estimated site carrying capacities. Populations limited to these sizes are especially vulnerable to snaring pressure. Further, isolated populations constrained to this range of sizes can be expected to suffer genetic deterioration and consequent declines over time even without snaring pressure. Supplementation from other, larger sites, or from captive facilities, could offset these issues and this is explored here. To see what it might take to keep populations of this size on the ground, supplementation rates of two individuals every 1-10 years are modelled, for population sizes (and carrying capacities) of Ni=K=25-200, with snaring pressure set at 20% offtake per year. The results are displayed in Table 15.

Table 15. Illustrating the effect on growth rate, extinction risk, population size and gene diversity, of supplementing populations of Ni=K=25-200 with 2 individuals every 1-10 years (with 20% snaring pressure).

		N=K							
a) stoch-r		25	50	75	100	125	150	175	200
2/year	1	0.06	0.03	0.08	0.08	0.01	0.00	0.00	0.00
2/2 years	2	0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01
2/5 years	5	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02
2/10 years	10	-0.05	-0.04	-0.04	-0.04	-0.03	-0.03	-0.02	-0.02
b) P(Ex)		25	50	75	100	125	150	175	200
2/year	1	0.07	0.01	0.01	0	0	0	0	0
2/2 years	2	0.38	0.19	0.13	0.07	0.04	0.03	0.03	0.03
2/5 years	5	0.8	0.54	0.37	0.29	0.2	0.13	0.11	0.08
2/10 years	10	0.96	0.72	0.51	0.39	0.29	0.19	0.15	0.11
c) N-All		25	50	75	100	125	150	175	200
2/year	1	21.98	40.7	67	90.11	90.34	99.96	117.8	125.8
2/2 years	2	11.94	24.95	35.77	51.7	64.5	83.03	95.75	108.14
2/5 years	5	2.58	9.77	19.27	29.3	43.41	57.26	71.76	88.89
2/10 years	10	0.43	5.04	13.53	22.73	35.57	49.17	65.88	92.38
d) GD		25	50	75	100	125	150	175	200
2/year	1	0.93	0.93	0.94	0.94	0.94	0.94	0.94	0.94
2/2 years	2	0.88	0.89	0.9	0.91	0.91	0.92	0.93	0.93
2/5 years	5	0.77	0.79	0.8	0.83	0.86	0.87	0.89	0.9
2/10 years	10	0.70	0.71	0.76	0.79	0.82	0.84	0.87	0.88

With snaring pressure set at 20% annual offtake, populations of at least 100, supplemented at 2 individuals per year, meet the viability definition set here, over the 50-year period (1% extinction risk or less).

Summary

- Muntjac captive populations are expected to grow consistently and be able to reach capacity and begin generating a harvest for release within 4-8 years.
- In absence of snaring pressure, wild populations are expected to exhibit more variable but still reliable growth, if they are seeded with at least 20 founders and can grow to at least N=50. Note that this is for a 50-year period only.
- Even in absence of snaring pressure, ongoing supplementation is likely to be required at smaller, isolated sites to prevent stochastic declines due to inbreeding accumulation and other chance factors.
- Snaring pressure of 20% annual offtake cannot be tolerated by populations of N=200 or less.
- Populations of less than N=50 cannot tolerate any snaring.
- Smaller sites are likely to be marginal for this species.

Note that the figures presented are draft, based on preliminary estimates of the species' biological parameters and their likely response to the environments and influences described.

STRIPED RABBITS

Introduction

Nesolagus is a genus containing three species of striped rabbit: the Annamite Striped Rabbit (*N. timminsi*), the Sumatran Striped Rabbit (*N. netscheri*), and the extinct species *N. sinensis*. Little is known about them and currently there are no *ex situ* populations.

The Annamite rabbit is categorised as Endangered (IUCN 2019) with indiscriminate snaring cited as the main cause of recent precipitous declines. However, recently several individuals have been found in the illegal wildlife markets in Indonesia and have been offered as pets online in Thailand (pers. Comm. A. Tilker). The species is restricted to wet, evergreen forest, such that much of its range falls within Vietnam, where snaring is particularly intense. Habitat for this species still remains and work is underway to mitigate threats (particularly snaring) at several sites, to levels that would allow populations to persist.

The Annamite rabbit project aims to restore viable populations at designated *in situ* sites, using rabbits bred at *ex situ* facilities in Vietnam.

The Sumatran rabbit is categorised as Data Deficient (IUCN 2019) and is restricted to the island of Sumatra. It is rarely sighted and recently from only two national parks (Bukit Barisan Selatan and Kerinci Seblat). It is strongly forest dependent. Habitat conversion to agricultural land is the most significant threat. It may be caught in snares but does not seem to be targeted either for food or the pet trade. There are currently no sites identified or being prepared for release.

The Sumatran rabbit project aims to establish and sustain a long-term *ex situ* population, as insurance against extinction.

It is assumed that the biology of these two species is similar enough for the same *ex situ* Baseline Model to be used. Beyond that, the different aims of these two projects require different scenarios and therefore different sets of models.

Baseline Models

No *ex situ* data are available for these species. Models were initially built using *ex situ* data from other lagomorph species, the New England Cotton-tails (NECT) (data provided by Craig Gibbs, NCET Coordinator for WCS Queens Zoo) and the Pygmy Rabbit (PR) (data provided by Kelli Walker, Oregon Zoo). These values were then adjusted by a wider group of experts based on the following assumptions:

Striped rabbits are adapted to a non-seasonal rainforest environment and are more closely related to hares than to rabbits. Therefore, it is likely that, compared to the *ex situ* analogues initially chosen:

- they have a longer reproductive life;
- they have fewer, smaller litters and invest more in maternal care.

An analysis of data from other hare species (i.e. those found in the "AnAge" Bibliographical Database) is shown below in Table 16 and was used to inform a revision of Baseline Model parameters:

Table 16. Data on lagomorph species sourced from the AnAge Bibliographical Database used to inform ex situ models for Annamite and Sumatran Striped Rabbits (*Nesolagus spp*.)

Species	Females Mature (days)	Gestation (days)	Litter size	Litters per year	Longevity (years)	Reference
Lepus timidus	266	50	2.0	2.1	18.0 (N=1 wild)	Angerbjorn & Flux 1995
Lepus europaeus	236	42	2.0	3.8	10.7 (N=1 captivity)	Weigl 2005
Silvilagus palustris	219	34	2.3	6	7.6 (N=1 captivity)	Weigl 2005
Lepus brachyurus	-	38	2.1	2.5	13.0 (N=1 captivity)	Weigl 2005
Lepus californicus	243	44	1.0	3.7	11.8 (N=1 captivity)	Weigl 2005
Mean	241	42	1.9	3.6	12.2	

The resulting parameters for the Captive Baseline Model are shown in Table 26.

Characteristics of the Captive Baseline Model

Deterministic projections (i.e. without stochastic influences on reproduction and mortality rates) show a population that grows at an annual rate of 20% (λ =1.209). Generation time (for both sexes) is approximately 2.5 years. With stochastic elements included a high degree of variability is introduced resulting in decreased average growth rate (stoc-r=0.035 ± 0.24) and 42% risk of extinction over the 50-year period (see Figure 15 for an illustration). The age structure of the Captive Baseline Model is illustrated in Figure 16, where the pattern of high early mortality is evident.

Table 17: Deterministic Baseline Model characteristics for Striped Rabbits

Deterministic rates	
Lambda (λ)	1.209
Generational growth (Ro)	1.507
Generation time (T)	2.44

Note that in this model the population is capped at N=50 and any surplus is reduced by additional mortality imposed randomly across all age-classes.

Stochastic rates	
Instantaneous growth rate (r)	0.035 ± 0.24
Gene Diversity (GD)	0.62 ± 0.16
Extinction Risk (PE)	0.42
N (All)	17.7 ± 19.59

Table 18: Stochastic Baseline Model characteristics for Striped Rabbits

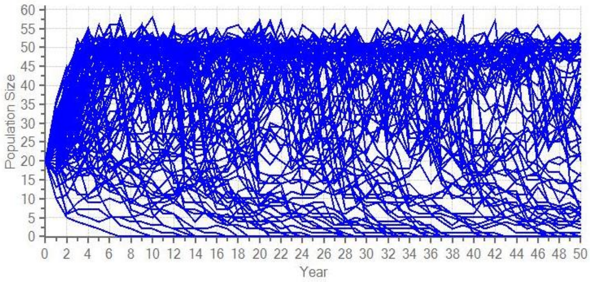
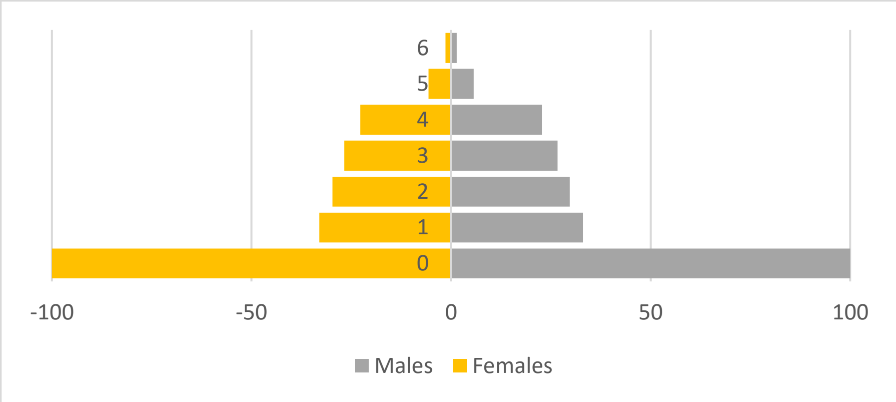


Figure 15. VORTEX visualisation of Striped Rabbit Captive Baseline Model

Figure 16. Age structure of the Captive Baseline Model for *Nesolagus spp.*



Sensitivity testing

There is high parameter uncertainty in the Captive Baseline Model. Each parameter in turn was varied across a plausible range of values to explore which have the greatest impact on model performance. The values used are shown in Table 19.

Table 19. Values used to test Captive Baseline Model sensitivity for *Nesolagus spp.* (Baseline Model values in red).

Parameters (biology)	**Tested values**
Age 1st offspring (f)	3,2,**1**
Age 1st offspring (m)	3,2,**1**
Maximum lifespan	4,5,**6**,7
% Breeding Females	70,80,**90**,100
Offspring number distribution (1; 2; 3)	[60;20;20]; [40;40;20]; **[20;60;20]**; [20;40;40]; [20;20;60]
Mort. Rates % [0;1]	87,77,**67**,57,47

Parameters (biology)	Tested values
Mort. Rates % [2;+]	[20;25;70;85]; [15;20;65;80]; **[10;15;60;75]**; [5;10;55;70]; [0;5;50;65]
Sex-Ratio (% male)	60;55;**50**;45;40

Figure 17. illustrates the results of the sensitivity tests. As shown, across the range of values modelled, **the annual mortality of age class [0;1]** has by far the biggest impact on Baseline Model performance. The breeding ages of females and males, the annual number of offspring and adult mortality are also influential. Lifespan and sex-ratio have less impact.

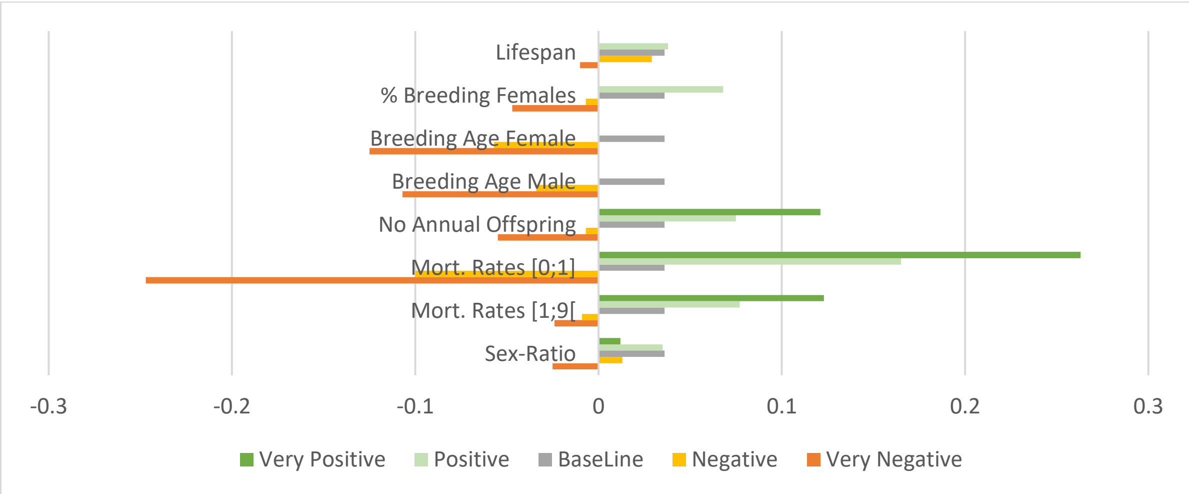


Figure 17. Results of sensitivity tests for the *Nesolagus* Captive Baseline Model. Growth rate (Stoc-r) is shown for each parameter variation.

Scenario Testing

To explore pertinent management questions the Striped Rabbit Baseline Model was modified to create a best estimate of the performance of a newly established captive population in Vietnam. Specifically, the new model deviates from the Baseline Model as follow:

- Female breeding rate was initiated at a low of 30% and reached 90% after three years, anticipating likely initial husbandry difficulties.
- Two “catastrophes” were added to the model: Disease and Human Error. Disease is assigned a 14% chance of occurrence each generation, with 50% less survival across all age-classes in the years where it occurs (after Reed et al. 2003). Human Error is assigned a 20% chance of occurring in the first three years (0% afterwards) and reduces survival to 80% of normal rates when it occurs.

- First year mortality rates are assumed to decrease over the first years of the program and are reduced from 67% in year 1 to 50% by year 3, again anticipating likely husbandry improvements.
- Most importantly, the captive **carrying capacity is based on the number of adults only**. For example, a population size of K=20 holds 10 adult females and 10 adult males. Juveniles are assumed to be released immediately or to be kept separately.

1a) What is the minimum number of founders required to establish a captive population that can grow to N adults (where N is between 10 and 100) and persist, with P(Extinction) < 1%, over 25 and 50yrs?

Models were built to explore this question and the results are summarised in the tables below.

Table 20. Fifty-year results: relationship between starting size (Ni), carrying capacity (K), and likelihood of extinction (P(Ex)).

P(Ex) - 50 yrs		K (adults)						
		10	20	30	40	50	75	100
	6	100	100	99	99	99	98	99
Ni	10	100	99	99	96	93	92	93
	20	-	98	91	80	77	69	64
	30	-	-	85	68	52	46	42
	40	-	-	-	55	44	30	25
	50	-	-	-	-	37	23	16

For the range of values considered, extinction risk is lowest for populations founded with at least 50 individuals and able to grow to N=100 but is still high (P(Ex)=16%.

Table 21. Twenty-five-year results: relationship between starting size (Ni) and carrying capacity (K), and likelihood of extinction (P(Ex))

P(Ex) - 25 yrs		K (adults)						
		10	20	30	40	50	75	100
	6	100	99	95	94	95	94	95
Ni	10	99	99	91	90	85	86	86
	20	-	70	58	52	54	52	51
	30	-	-	40	45	30	30	26
	40	-	-	-	27	18	16	13

	50	-	-	-	-	11	10	7

Over the shorter timeframe extinction risks are lower but even with K=100 and a starting size of Ni=50, 7% of simulated populations went extinct.

In these models there is a critical period of time (the first 3 years) during which populations are particularly vulnerable to a downward trajectory. This is due to the inclusion in the models of lowered breeding success and increased mortality during that period, while husbandry techniques are being honed. Beyond this period, if enough animals have survived (app. >20), most populations can grow to reach carrying capacity. Such populations usually reach (or recover to) 50 individuals in 8 to 12 years.

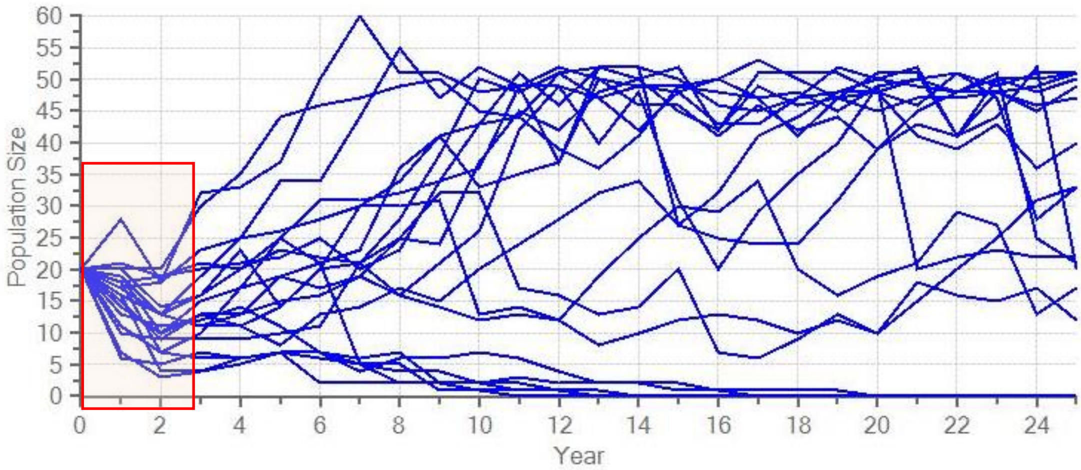


Figure 18. Striped Rabbit simulations highlighting the most vulnerable three-year period.

1c) What is the impact of adding 2 extra females every 2 years?

The following tables illustrate the comparison between supplemented and non-supplemented populations in terms of extinction risk.

Table 22. Fifty-year results: relationship between starting size (Ni), carrying capacity (K), and likelihood of extinction (P(Ex)) with no supplementation.

P(Ex) - 50 yrs		K (adults) – no supplementation					
		20	30	40	50	75	100
Ni	10	99	99	96	93	92	92
	20	98	91	80	77	69	67
	30	-	85	68	52	46	44
	40	-	-	55	44	30	32

P(Ex) - 50 yrs		K (adults) – with supplementation					
		20	30	40	50	75	100
Ni	10	67	59	55	56	56	58
	20	39	22	18	14	15	17
	30	-	13	10	10	8	7
	40	-	-	9	5	3	2

Table 23. Fifty-year results: relationship between starting size (Ni), carrying capacity (K), and likelihood of extinction (P(Ex)) with 2 females supplemented every 2 years.

Regular supplementation significantly improves the prospects of the population though only those founded with at least 40 individuals and able to grow to 100 show extinction risk close to zero (P(Ex)=2%).

2a) How many juveniles can be harvested each year, from populations starting at N=50, 75, 100, 125 and 150 adults (with stable age-structures and even sex-ratios)?

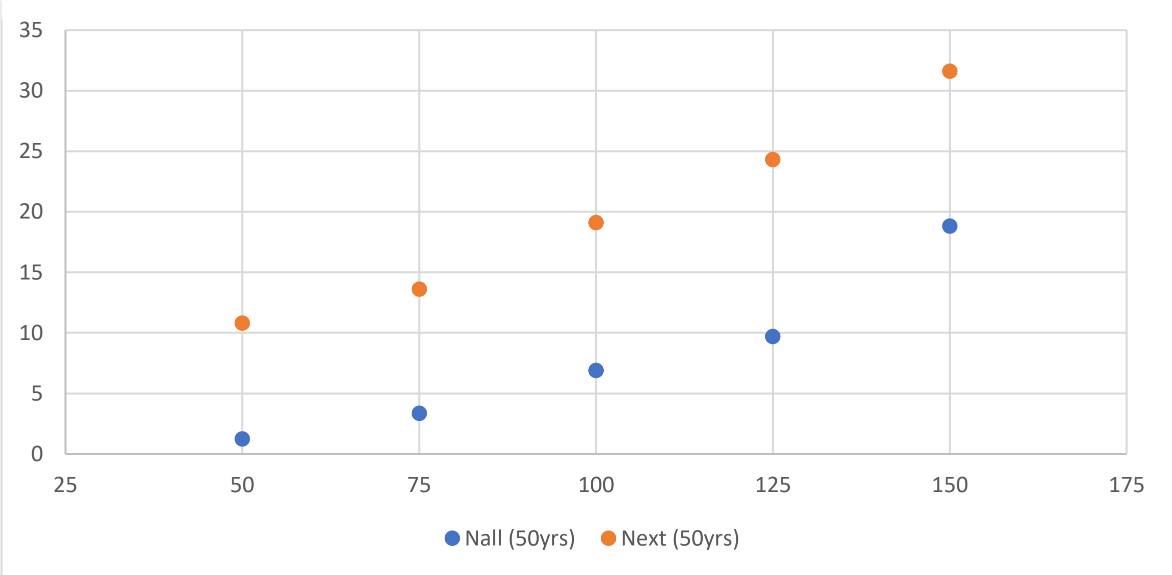
For populations surviving the early risk period and growing to capacity, regular harvests should be possible. The potential size of those harvests, for different sized populations, is explored here.

Table 24. Fifty-year results: illustrating expected annual harvest of juveniles from populations of different sizes. N-All includes mean annual harvest across all iterations (including those that go extinct within the timeframe). N-Ext includes mean annual harvest of juveniles only for the subset of populations that survive to 50 years.

Ni=K	N-All(50yrs)	N-Ext (50yrs)
50	1.24 ± 3.4	10.8 ± 5.7
75	3.36 ± 6.6	13.6 ± 8.1
100	6.9 ± 10.6	19.1 ± 10.2
125	9.7 ± 13.3	24.3 ± 12.1
150	18.8 ± 13.3	31.6 ± 16.7

As illustrated in Table 25 and Figure 19, if husbandry challenges can be overcome in the early years of a captive programme. Allowing the population to grow rapidly to capacity and avoid the otherwise high risk of early extinction, expected harvest rates are between 10 and 31 offspring per year, for adult populations ranging from N=50-150 respectively.

Figure 19. Fifty-year results: illustrates expected annual harvest of juveniles from different population sizes. N-All includes mean annual harvest of juveniles across all iterations (including those that go extinct within the timeframe). N-Ext includes mean annual harvest only for the subset of populations that survive.



2b) How does that change when the starting population begins with a kinship of 0.125, 0.25 and 0.5?

So far, models have assumed starting populations comprising unrelated individuals. It may not be possible to achieve this. For example, founder individuals from trade may be litter mates. A series of models were built to test the impact of higher levels of inter-relatedness in the population from the outset. The results are shown below in Table 26 and Figure 20.

Table 25. Fifty-year results: illustrating expected annual harvest of juveniles for populations of different sizes, beginning with different average levels of inter-relatedness (mean kinship).

	Average Mean kinship			
Ni=K	0	0.125	0.25	0.5
50	1.24 ± 3.4	0.2 ± 0.8	0.1 ± 0.2	0.0 ± 0.0
75	3.36 ± 6.6	0.4 ± 1.6	0.2 ± 1.1	0.0 ± 0.0
100	6.9 ± 10.6	3.24 ± 7.0	0.9 ± 3.8	0.0 ± 0.0
125	9.7 ± 13.3	4.44 ± 8.6	1.9 ± 5.5	0.0 ± 0.5
150	18.8 ± 13.3	8.29 ± 13.6	3.2 ± 8.7	0.1 ± 1.0

As shown in Table 25, incrementally increasing the inter-relatedness of the starting population depresses growth and reduces harvesting potential in the population. For example, for a captive population of 150 adult rabbits, increasing population average mean kinship from 0 – 0.25 reduces expected annual harvest potential from approximately 18 to 3 animals.

Sumatran Striped Rabbit Models

Unfortunately, it was not possible in the time available to proceed with captive models for Sumatran Striped Rabbits. However, due to the presumed biological similarities of the two species the above models for the Annamite Striped Rabbit would likely be equally relevant to the Sumatran Striped Rabbit.

Summary

- While populations of Striped Rabbits have high growth potential they are vulnerable to extinction in the early stages of any programme, while husbandry is being established.
- Populations that survive this early period can reliably generate annual harvests of juveniles for release (models estimate approximately 10-30 individuals per year, from populations numbering 50 – 150 adults respectively).
- To avoid high extinction risks populations would ideally begin with 40-50 individuals and be able to grow to N=75-100 adult rabbits. This is likely to be unachievable. With smaller founding populations, early and consistent husbandry success is particularly important.
- Beginning with related individuals depresses productivity and leads to reduced capacity to generate juveniles for release. This depression also occurs over time in populations that begin with unrelated individuals but receive no further supplementation from outside sources.

Table 26. Captive Baseline Model Parameters for Striped Rabbits, *Nesolagus spp.*

Vortex Parameters	Baseline Value	Details
Period modelled	50 years	To allow investigation of long-term insurance programme prospects (Sumatran only)
Inbreeding depression severity	3.15 LEs	Default based on captive population studies
Percent due to recessive alleles	50%	Default based on studies of a limited number of species
EV correlation between reproduction and survival	None	No. Factors affecting the two are not coupled *ex situ*
Breeding system	Monogamous	Representing likely management approach *ex situ*
Age of first offspring	1 year	Both sexes
Maximum age of reproduction	6 years	Assume the same for both sexes
Maximum lifespan	6 years	Mean=12 from AnAge. Most animals expected to live less long.
Maximum number of broods per year	2 (average 1.5)	Mean=3.6 from AnAge and 3 observed in NECTs, though assume *Nesolagus* less fecund under mgmnt.
Maximum number of progeny per brood	3 (average 2)	Assume fewer than observed for NECTs (4-6). Mean=1.9 from AnAge.
Sex-ratio at birth in % males	50%	No data to support a sex-ratio skew at birth
% adult females breeding (S.D)	90% (5%)	Est. range 80-100%. All females expected to breed in most years though success may be lower initially. Experience from NECTs and PRs indicate some females are unsuited to *ex situ* mgmt and do not breed successfully. Assume same here.
Distribution of offspring number:		
1 Offspring	20%	Reduced from numbers observed for NECTs (105 offspring and up to 6)
2 Offspring	60%	
3 offspring	20%	
Female & Male mortality rates		SD in mortality due to EV set to 10% of mean in each age-class
Age 0 to 1	67%	NECTs and PRs show lower survival in the first litter of the year. Mortality assumed to be greater for Striped Rabbits. Gt. Malayan Chevrotains show 48-53% first year mortality though population highly inbred.
Age 1 to 3	10%	Function applied: 10+(5*(A>2))+(35*(A>3))+(25*(A>4))
Age 3 to 4	15%	
Age 4 yrs	50%	
Age 5+	75%	
% Males in breeding pool	100%	All males have an opportunity to breed.
Initial population size	20 ADULTS (10M;10F)	In the captive population young will be released, founder adults retained.
Carrying capacity	50 ADULTS (25M;25F)	Carrying capacity is set to 50 adults individuals for testing and verification.

VIETNAM PHEASANT

Introduction

The Vietnam Pheasant *Lophura edwardsi* (including *L. hatinhensis* which is considered a variant of the Vietnam Pheasant) is only known from a small area of central Vietnam, where it occurred in wet forest below 300m. It is probably extinct in the wild, but some 1,500 birds, derived from founders caught in 1924–1930, survive in captivity (Collar 2020).

Efforts are already underway to restore this species to wild sites. There is a Vietnam Pheasant Recovery Team and a 2015-2020 Vietnam Pheasant Action Plan. The Action Plan emphasises: 1) **protection and management of known key sites** (listed from north to south: Ke Go – Khe Net; Khe Nuoc Trong – Bac Huong Hoa (or Truong Son IBA); and Dakrong – Phong Dien forest blocks); 2) **captive breeding** in Vietnam for eventual release to the wild; and 3) **field surveys** to locate any remaining wild populations and **studies to fill information gaps** related to basic ecology, captive management and the feasibility of reintroduction.

In 2014, Viet Nature launched a long-term project (with a 30-year vision) in one of the key sites - Khe Nuoc Trong (20,000 ha), involving intensive protective management at the site and its wider landscape. In 2015, a 30-year lease (2015-2045) was obtained for 768 ha of forest environment at this site that can be used as a future location for reintroduction. With national and international partners (including from the international *ex situ* community), Viet Nature was able obtain a 5-ha site near Khe Nuoc Trong and begin development of the first Vietnam pheasant conservation breeding station in Vietnam, with an associated visitor and education centre.

EAZA has a Long-Term Management Plan (LTMP) in place covering the global *ex situ* population (Kapic et al 2020), from which birds will be drawn to found the new captive population in Vietnam. According to the LTMP, in December 2018 there were 1046 living Vietnam Pheasants registered in the studbook, grown from no more than 39 wild origin birds (29 of *L. edwardsi*, 10 of *L. hatinhensis*) most of which arrived in captivity between 1924-1930 (Collar 2020). Living birds are distributed globally but are mainly concentrated in Europe.

The species has now been maintained in captivity for as many as 35 generations (Collar 2020) without genetic supplementation. This raises concerns about future suitability for release, which may be irreversibly compromised by low-levels of genetic diversity, captive selection and loss of wild traits (see Collar 2020). Escaped birds have survived well in the wild in the UK (J. Corder pers. comm.) which, though a small sample, is cause for optimism. To mitigate some of the inherent challenges, only parent-reared birds will be used to found the Vietnamese population, and only birds parent-reared in Vietnam will be considered for release. Soft release protocols are being designed to support a gradual transition of birds from captive to wild conditions.

As currently conceived, the Vietnam Pheasant recovery project consists of three broad phases:

1) create a subset of the international captive population comprising facilities that are only generating parent-reared birds;
2) use this subset to generate birds for transfer to Vietnam, to establish a captive population of ≈300 individuals, at purpose-built facilities;

3) use this Vietnamese captive population to generate birds for soft-release at well protected and ecologically suitable wild sites.

Though much enabling work has been done to support this approach, there remain areas of uncertainty that make it difficult to run useful population viability analyses at this time. It was agreed with the group that for the current exercise, preliminary models would be built and sensitivity tested, but that more detailed scenario testing would await the results of further data collection and conservation planning discussions within the group.

Summary of Findings to Date.

For a successful captive model (Vietnam)	Findings	Notes
How many founders?	> 50	Note: "Founders" here are birds from the Int. population.
How large a population?	> 200	Size needed to retain ≈90% GD for 50 years and P(Ex)=0.
What rates of breeding & survival?	As for baseline models	See Table 29.
What level of genetic management?	High	Mean kinship management by studbook is intended.
How long before releases can begin?	TBC	No data yet on how well parent-reared subset performs.
What size, composition & frequency of release cohorts could be possible?	25-45 juveniles per year (from 25.25 adults)	Preliminary only - no data yet on how well the parent-reared subset will perform.

For a successful wild model	Findings	Notes
What is the minimum viable population size?		To be developed pending further discussion and data collection.
How many animals should be in a release cohort?		
Of what age and sex?		
What release frequency?		
How many years to re-establishment?		
How much ongoing supplementation will be needed and from where?	Not possible as likely extinct in the wild.	

Meta-population question		
With plausible inputs can we create a successful scenario?	TBC	

Baseline Models

Captive population data are available through the EAZA LTMP and SSP. Using this, and additional data and advice from the PVA group, two Captive Baseline Models were constructed, both for currently hypothetical populations: one for an intensively managed subset of the existing international population that uses only parent-rearing; and one for a new population in Vietnam. These differ only in the values entered for mortality in the 0-1 age-class. The International Baseline Model uses values calculated from captive population data (76% for females; 74% for males), while the Vietnam Baseline Model uses a reduced value estimated by the PVA group (50% for both sexes). The rationale for this is as follows: The 0-1 age-class follows each bird from the egg stage to 1 year after laying, thereby encompassing hatching failure as well as post-hatch mortality. In Europe, some of the hatching failure can be attributed to the harsh winters (though how much is not explicitly recorded, hence the need for estimation). This source of mortality is not expected in the Vietnam population and was removed from the models accordingly.

No data are available for wild populations. A hypothetical wild model was created by customising the captive models as follows:

- Breeding system is changed from monogamous to polygynous.
- Lifespan is reduced from 14 years in captivity to 10 years.
- Inbreeding impact is increased to reflect greater stresses.
- Annual percentage of females breeding is increased.
- Early mortality is increased.

Hatching success data

Calculating mortality in the 0-1 age-class required collection of additional information on hatching success (that is, the percentage of eggs laid that hatch successfully). Though data were available on clutch size variability, and on post-hatch mortality (from studbook data), initially there were no date on hatching success, which connects these two pieces of information to create a plausible life-table. Hatching success data was therefore collected by members of the expert group (Jan Dams and Hannah Ahern) via a survey of holders. The results were as follows:

Table 27. Hatching success data gathered for this project.

Where clutches were manipulated to prevent hatching, data were excluded from calculations (grey shading).

Female	Location	Age of female	Clutch size	Hatch	% Hatching Success
A23	Harewood Bird Gardens	1	3	0	Excluded
A23	Harewood Bird Gardens	2	5	1	20.00
A23	Harewood Bird Gardens		5	0	Excluded
AVFG695F1911016	Vietnam	1	4	1	25.00
AVFG695F1911016	Vietnam	2	9	2	22.22
B2253	Jersey Zoo	8	5	2	40.00
B2253	Jersey Zoo	7	7	2	28.57
B2689	Jersey Zoo	6	3	3	100.00
B2689	Jersey Zoo	8	3	0	0.00
B3304	France + Jersey	15	2	2	100.00
B3304	France + Jersey	12	4	2	50.00
B3304	France + Jersey	9	5	0	0.00
B3304	France + Jersey	13	5	0	0.00
B3365	Jersey Zoo	4	6	2	33.33
B7393	Jersey Zoo	2	5	5	100.00
B7393	Jersey Zoo	6	5	2	40.00
B7393	Jersey Zoo	2	8	0	0.00
B7532	France	2	5	4	80.00
B7532	France + Jersey	5	5	3	60.00
P6	Harewood Bird Gardens	2	4	3	75.00
P6	Harewood Bird Gardens	3	6	3	Excluded

Table 28. DRAFT Vietnam Pheasant Parameters: Baseline Models – Captive (INT), Captive (VIET), Wild

Vortex Parameters	Captive (INT)	Captive (VIET)	Wild	Details (Data drawn from the EAZA LTMP and SSP, modified with advice from the working group)
Period modelled	50 years	50 years	50 years	To allow investigation of long-term prospects
Inbreeding depression severity	3.14 Lethal Equivalents	3.14 Lethal Equivalents	6.29 Lethal Equivalents	Default based on captive & wild studies
Percent due to recessive alleles	50%	50%	50%	Default based on studies of a limited number of species
EV correlation between reproduction and survival	0.0	0.0	0.5	No. Factors affecting the two are not coupled *ex situ.* Not known for the wild.
Breeding system	Monogamous	Monogamous	Polygamous	Difference represents likely management approach *ex situ*
Age of first offspring	1 year	1 year	1 year	Both sexes
Maximum age of reproduction	14 years	14 years	10 years	Assume the same for both sexes and no senescence in wild.
Maximum lifespan	22 (M); 16 (F) years	22 (M); 16 (F) years	10 years	Differs between sexes in captivity (based on data). No distinction made in wild (no data)
Maximum number of broods per year	1	1	1	Assuming parent rearing.
Maximum number of progeny per brood	7	7	7	From captive data and expert opinion.
Sex-ratio at birth in % males	50%	50%	50%	No data to support a sex-ratio skew at birth
% adult females breeding (S.D)	70% (5%)	70% (5%)	80% (5%)	Estimates – much uncertainty around this (parent rearing rates and wild values not known but assumed higher)
Distribution of clutch sizes (%):				
1, 2, 3, 4, 5, 6, 7	0, 5, 20, 20, 40, 10, 5	0, 5, 20, 20, 40, 10, 5	0, 5, 20, 20, 40, 10, 5	Modified from captive data (i.e. capped at 7 eggs)
Female & Male mortality rates (%)				SD in mortality due to EV set to 10% of mean in each age-class
Age 0 to 1	76 (F); 74 (M)	50%	80 (F); 80 (M)	Assume higher mortality in wild population
Age 1+	10% - 75%	10% - 75%	10%-50%	Function applied (e.g.): 10+((A>1)*(0))+((A>12)*20)+((A>17)*45) – Captive.
% Males in breeding pool	100%	100%	25%	All males have an opportunity to breed in captivity only.
Initial population size	50 ADULTS (25M;25F)	50 ADULTS (25M;25F)	100 ADULTS (50M;50F)	In harvest models the captive population young are released, adults are retained and replaced as needed (with young)
Carrying capacity	100 ADULTS (50M;50F)	100 ADULTS (50M;50F)	100 ADULTS (50M;50F)	Carrying capacity is set to 100 adults individuals for testing and verification.
Catastrophes	-	-	1 (Reed et al.)	Based on Reed et al – study of catastrophes across multiple species showed a 14% chance per generation of a population crash of 50%. Included here as 5% overall frequency, 50% survival in year of occurrence.

Baseline Model Performance

With the model values described in Table 29, deterministic projections (i.e. without stochastic influences on reproduction and mortality rates) show a population that grows at an annual rate of approximately 68% per year (r=0.5180; λ =1.679) and has a generational growth rate of Ro=5.960. This is extremely high and difficult to verify in absence of data on observed, unconstrained growth of a captive population (all data are for managed populations in which reproduction is often curtailed to avoid exceeding carrying capacity). Generation time (T) is 3.45 years. Stable age structure for this modelled population is illustrated in Figure 21.

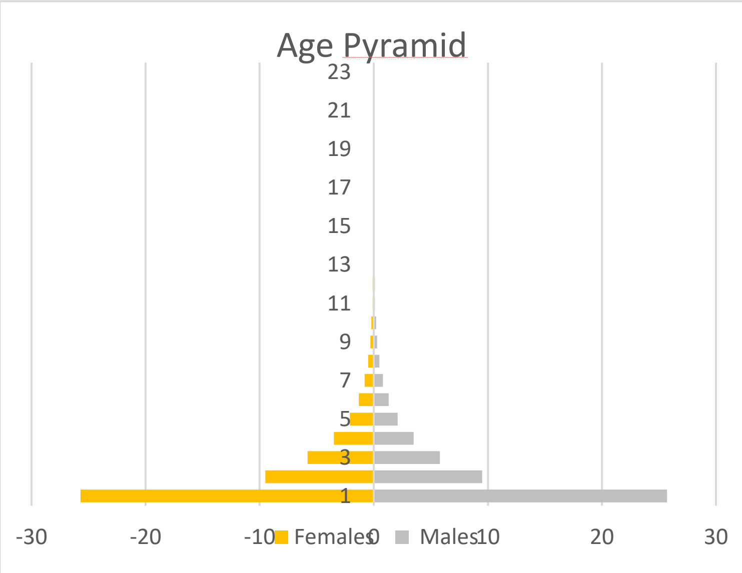
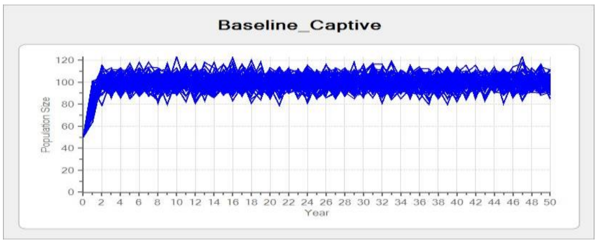


Figure 21. Age-pyramid portraying a stable-age structure for a captive population of Vietnam Pheasant, calculated through VORTEX. Proportions of males and females are shown on the X-axis; age-classes are shown on the Y-axis.

Including stochastic elements in the baseline model (i.e. inbreeding, demographic stochasticity and year-to-year environmental variation in age-specific vital rates) reduces the average growth rate to r=0.4692 with relatively low year-to-year variation around that rate (SD=0.098). At the population size modelled (N=100) none of the simulated populations go extinct over the 50-year period and the population remains at or close to capacity throughout (N at 50 years=99.89). Gene diversity at 50 years is below the commonly applied 90% threshold.

Deterministic rates	
Lambda (λ)	1.679
Generational growth (Ro)	5.960
Generation time (T)	3.45
Stochastic rates	
Stoc-r	0.4668
N(All) at 50 years	100.16
P(Ex) at 50 years	0.0000
GD at 50 years	0.8241

Table 29. Deterministic and stochastic rates for the Captive Baseline Model (shown below) for the Vietnam Pheasant.



Sensitivity Testing

Table 30: Parameters and values considered in sensitivity tests for the Vietnam Pheasant Captive Baseline Model.

Parameters (biology)	Tested values
Age 1st offspring (f)	4,3,2,**1**
Age 1st offspring (m)	4,3,2,**1**
Age last reproduction (f)	8,10,12,**14**,16,18
Age last reproduction (m)	8,10,12,**14**,16,18
Maximum lifespan	16,18,20,**22**,24,6
% Breeding Females	50,60,**70**,80,90
Offspring number distribution (3;4;5)	[60;20;20]; [40;40;20]; **[20;60;20]**; [20;40;40]; [20;20;60]
Mort. Rates % [0;1]	87,77,**67**,57,47
Mort. Rates % [2;+]	[20;25;70;85]; [15;20;65;80]; **[10;15;60;75]**; [5;10;55;70]; [0;5;50;65]
Sex-Ratio (% male)	60;55;**50**;45;40

Across the range of values tested, the following factors were most influential in driving or restricting population growth:

- Year 0-1 and young adult mortality.
- Percentage females breeding each year.
- Clutch size.

Less influential were:

- Late adult mortality.
- Sex-ratio.
- Percentage of males in the breeding pool.

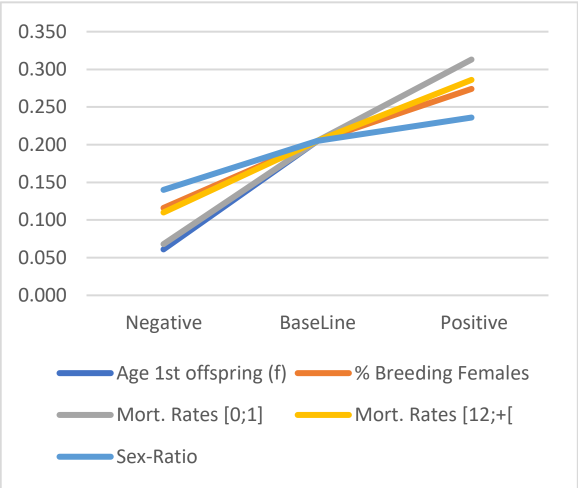


Figure 20. Sample of sensitivity test results for the Vietnam Pheasant Captive Baseline Model

Testing initial size and carrying capacity

In general, population performance improves with increased size. The influence of both starting population size and carrying capacity, on population extinction risk and gene diversity retention, were tested. The results are shown in Tables 32 and 33. As shown, to achieve high levels of viability (P(Ex)=0.00 or close to it) populations are ideally founded with at least 50 birds and able to grow to at least N=100 (including adults and juveniles). Retaining 90% gene diversity over the 50-year period requires larger population sizes and, in these models, can be achieved with a starting population of 50-100 birds and a carrying capacity of 500-200 respectively (that is, with fewer founders and therefore less starting gene diversity, populations must grow rapidly to larger size in order to achieve the same retention results).

Table 31. Impact on extinction risk of varying starting population size (Ni) and carrying capacity (K).

50 yrs	P(Ex)	K						
		10	25	50	75	100	200	500
Ni	10	1	0.93	0.80	0.74	0.70	0.72	0.71
	25	-	0.84	0.32	0.20	0.17	0.16	0.15
	50	-	-	0.29	0.07	0.03	0.03	0.02
	75	-	-	-	0.05	0.02	0.01	0
	100	-	-	-	-	0.02	0	0

Table 32. Impact on gene diversity retention of varying starting population size (Ni) and carrying capacity (K).

50yrs	GD	K						
		10	25	50	75	100	200	500
Ni	10	0	0.46	0.59	0.59	0.62	0.65	0.66
	25	-	0.47	0.64	0.7	0.76	0.8	0.8
	50	-	-	0.65	0.75	0.81	0.88	0.91
	75	-	-	-	0.76	0.82	0.89	0.93
	100	-	-	-	-	0.83	0.9	0.94

Testing resilience to snaring pressure

Snaring is likely to be one of the challenges faced by birds released to the wild. A series of models were run to assess the ability of populations of varied size, to tolerate different levels of snaring pressure. The results are shown in Tables 34 & 35. As shown, none of the population sizes modelled can tolerate snaring intensities of 10% annual offtake, and only populations of 150 or more show a low risk of extinction at snaring levels of 5% (P(Ex)=0.06). Even though populations of 150-200 can withstand a snaring intensity of 5%, population size is measurably depressed, as shown in Table 35.

Table 33. Shows the impact on extinction risk of different levels of snaring intensity (as annual % offtake), for populations of different sizes.

50 yrs	P(Ex)	Ni=K					
		25	50	75	100	150	250
Snaring	0%	0.84	0.27	0.07	0.02	0	0
	5%	0.98	0.73	0.39	0.21	0.06	0.01
	10%	1	0.97	0.9	0.74	0.48	0.22
	20%	1	1	1	1	1	1
	30%	1	1	1	1	1	1
	50%	1	1	1	1	1	1

Table 34. Shows the impact on proportion of carrying capacity occupied, of different levels of snaring intensity (as annual % offtake), for populations of different sizes.

50 yrs	N/K	N=K					
		25	50	75	100	150	250
Snaring	0%	0.40	0.56	0.71	0.78	0.87	0.93
	5%	0.24	0.28	0.37	0.47	0.61	0.76
	10%	0.28	0.14	0.13	0.20	0.23	0.33
	20%	0.00	0.00	0.00	0.00	0.00	0.02
	30%	0.00	0.00	0.00	0.00	0.00	0.00
	50%	0.00	0.00	0.00	0.00	0.00	0.00

Future modelling work

In reviewing this work, the Vietnam Pheasant Recovery Team identified several areas in which further modelling work would be useful:

- Maximum lifespan of 10 years may be too optimistic for an introduced wild population. The Team recommends testing the impact of reducing this to five years.
- Hatching success is still estimated from only a few clutches and institutions – checking and expanding this dataset would be helpful.
- 2022 was a good breeding season in terms of number of chicks produced. This may be part of normal inter-year variation in vital rates, or it may signal a general upturn in breeding success. This should be monitored closely and the potential impact of such an upturn on overall population performance tested in future modelling work.
- Work is ongoing to identify the optimum ages for releasing birds. Once this is done the models could revisit the question of potential harvest to investigate the size of breeding population needed to generate enough birds of the right age, over a given period.
- It would be useful to gather data and estimates relating to disease outbreaks (such as Avian Flu) that could affect Vietnam Pheasants, so that this can be incorporated more explicitly into the models (at present disease is included within annual mortality alongside other factors).
- Khe Go is a key site being considered for reintroduction for this species and its inclusion in site carrying capacity estimates would therefore be of value.

Summary

- With present data and estimates the Captive Baseline Model exhibits optimistic growth rates which cannot easily be verified because:
    - current data on growth are for living populations that are managed to prevent surplus and, therefore, are not necessarily a good indicator of biological potential for growth.
    - even if the above bias could be corrected for, transitioning to solely or mainly parent-rearing, may change growth potential.

  Therefore, until more information is available on how parent-rearing performs, and on how it performs unconstrained by reproductive management, these optimistic values should be treated with caution.
- Preliminary analyses indicate that for high levels of viability and gene diversity retention over 50 years, captive populations are ideally initiated with more than 50 birds and able to grow to more than 200. These are initial estimates only and subject to the same caveats as above.
- Current wild population models are more conservative than captive ones, though probably still optimistic. These population models do not tolerate snaring intensity at even the lower end of current estimates for that risk (10-20%). Therefore, preparation of wild sites may need to ensure snaring intensities are maintained at well below this level.
- As the program develops and more information is gathered, refinements can be made to the models to improve their value to conservation planning discussions.

ANNAMITE CRESTED ARGUS RHEINARDIA OCELLATA

Introduction

The Annamite Crested Argus, *Rheinhardia ocellata*, though previously more widespread, is now restricted to the Annamite Mountains where it is resident in primary and secondary evergreen forest from sea-level up to 1,500 m and has been seen at 1,700-1,900 m on the Da Lat Plateau. In 2021, it was categorised as Critically Endangered by the IUCN. The basis for the listing is a suspected rapid loss of abundance in this formerly common species driven by intensive industrial-level snaring in the past decade, in tandem with increasing rates of forest cover loss, allowing greater access to trappers and reducing the extent and quality of forested habitat within its range (Birdlife International 2021). Most recently, individual Annamite Crested Argus Pheasants have been showing up in the Indonesian bird markets and online in Thailand creating a new threat for the species (C. Shepherd, MONITOR, pers comm.).

As for other projects within the wider Annamites species recovery initiative, the aim is to establish a captive population in facilities within Vietnam, which will be capable of generating birds for release to suitably prepared wild sites. Only parent-reared birds will be released. Based on experience with other species there is an anticipated need for at least 25 pairs in the captive facility (Dr Murata pers. comm.). Though only 10 pairs are currently planned for there will be scope to expand.

Currently, the Annamite Crested Argus is held at Yokohama and Saigon Zoos, though in small numbers (n=28 from 13 founders as of July 2022). Captive protocols have been developed at Yokohama Zoo, where breeding has been successful to date.

Due to time and resource constraints the population viability analysis for this species did not extend to scenario testing. Information was gathered from specialists and baseline models were built and tested. Some preliminary recommendations have been made based on these analyses. The models used are fully described in these pages and can be reconstructed for future analyses once further conservation planning discussions have been held by the group.

Summary of Findings to Date

For a successful captive model (Vietnam)	Findings	Notes
How many founders?	≥ 24	For a 50-year program retaining 90% GD, zero extinction risk and positive growth and with K≥100.
How large a population?	K≥100	For a 50-year programme starting with at least 24 founders. At stable-age structure this would comprise approx. 75 adults and 25 juveniles (even sex-ratio)
What rates of breeding & survival?	Baseline	50% females breed annually; 43-48% Year-1 mortality; 5% annual adult mortality in younger adults, 25% in older adults.
What rate of supplementation?	None	No supplementation is required in this scenario.
What level of genetic management?	Intensive	A monogamous breeding system is assumed with pairs re-shuffled each year. To achieve equivalent genetic results is likely to require intensive monitoring and management of pairings.
How long before releases can begin?	15-40yrs	With 24 fdrs and K=100 – dependent on husbandry success
What size, composition & frequency of release cohorts could be possible?	4 birds per year aged 1-2	Starting at a carrying capacity of 100 (juveniles & adults). This number would increase with increased %age of females breeding and/or reduced mortality in early age-classes.

For a successful wild model	Findings	Notes
What is the minimum viable population size?		Not yet discussed.
How many animals should be in a release cohort?		
Of what age and sex?		
What release frequency?		
How many years to re-establishment?		
How much ongoing supplementation will be needed and from where?		

Meta-population question		
With plausible inputs can we create a successful scenario?	?	Not discussed yet.

Baseline Model Information

Captive Baseline Model

Few captive data are available for the Annamite Crested Argus. The known captive population of twenty-eight animals (as of July 2022) grew from thirteen founders and is distributed across two institutions (Yokohama and Saigon Zoos). Model parameter values are drawn from this population and from a larger population of a similar species, the Great Crested Argus (*Argusianus argus*) for which there is a larger living population (N=67) and for which more than 200 individual bird records have been gathered over time. This population is held in North American institutions and is managed through an AZA program (see Lynch & Russnogle 2019). Though still a small sample, the group agreed that this would provide reasonable estimates for parameters such as age at first and last breeding, lifespan, age-specific mortality, and offspring number distribution. As the AZA population is subject to coordinated management, which include constraints on breeding to avoid surplus production, reported population statistics are not necessarily a good basis for estimating population growth rate potential or annual female breeding rates. For these values estimates are made using a combination of Annamite Crested Argus information and the views of the experts.

Hatching success data

No hatching success data were available for this species. Therefore, the models are structured so that “birth” is taken as hatch date. That is, offspring number is defined as the number of hatchlings generated and not the number of eggs laid (note that for Vietnam Pheasants the models begin at the egg stage).

Wild Baseline Model

No data are available for wild populations. A hypothetical wild model was created by customising the captive models as follows (see Table 36 for details):

- Inbreeding severity is increased from 3.14 Lethal Equivalents (the Vortex default for captive populations) to 6.29 Lethal Equivalents (the default for wild populations).
- The social system is switched from monogamous to polygynous in accordance with wild observations. Due to the expected inter-male competition, the percentage of successfully breeding males is reduced (to 25%) and early male mortality is increased.
- Maximum lifespan (and of reproduction) is reduced to 15 years to reflect harsher conditions and the absence of disease management or veterinary intervention.
- The average annual breeding rate for females is increased from 50% in captivity to 80% in the wild.

Table 35: DRAFT Annamite Crested Argus Parameters: Baseline Models – Captive (VIET) and Wild

Vortex Parameters	**Captive (VIET)**	**Wild**	**Details (based on Yokohama Zoo data on Annamite Crested Argus, and from AZA population data on an analogue species, the Great Argus, *Argusianus argus*, modified with advice from the working group).**
Period modelled	50 years	50 years	To allow investigation of long-term prospects
Inbreeding depression severity	3.14 Lethal Equivalents	6.29 Lethal Equivalents	Default based on captive & wild studies
Percent due to recessive alleles	50%	50%	Default based on studies of a limited number of species
EV correlation between reproduction and survival	None	None	Factors affecting the two are not coupled *ex situ*
Breeding system	Monogamous (short-term)	Polygynous	Difference represents likely management approach *ex situ*. In Japan management best reflects the short-term monogamy option in VORTEX (pairs re-shuffled each year); in the US it better reflects the long-term monogamy option (pairs stay together until one or other dies or is removed). In the wild the species is polygynous (Birdlife International 2001).
Age of first offspring	2 years	2 years	Assume same for both sexes. AZA Great Argus males have bred from 2-21yrs and females from as early as 1 year but more commonly from 2-3 and up to 25 yrs.
Maximum age of reproduction (F/M)	20 years	15 years	AZA data for Great Argus indicate breeding into mid-twenties is possible but slows down through late teens. Assumed the same for both sexes and no reproductive senescence in wild.
Maximum lifespan	24yrs	15 years	Maximum observed for Great Argus=28yrs but is commonly less. Median life expectancy for birds surviving their first year is 12.4 yrs. Maximum lifespan estimated at 24 yrs by the group. Assumed to be reduced in the wild (no data).
Maximum number of broods per year	1	1	Assuming parent rearing (2 broods are possible under artificial rearing).
Maximum number of progeny per brood	4	4	From captive data.
Sex-ratio at birth in % males	50%	50%	No data to support a sex-ratio skew at birth
% adult females breeding (S.D)	50% (5%)	80% (8%)	Unable to discern from AZA Great Argus data due to the influence of recommendations for breeding management. Breeding success at Yokohama Zoo is high to date but the sample is small. Baseline model assumes 50% for captive, 80% for wild.
Offspring number (as % of clutches):	55%(1); 42%(2); 2.5(3); 0.5(4).	55%(1); 42%(2); 2.5(3); 0.5(4).	AZA Great Argus report lists mean chicks hatched per clutch as varying from 1-4 with a mean of 1.47 and a distribution of sizes as shown. Wild reports for Annamite Crested Argus indicate 2 eggs per clutch with no estimate given of hatching success or typical annual clutch number. In absence of other data the captive distribution is assumed.
Female & Male mortality rates (%)			**SD in mortality due to EV set to 10% of mean in each age-class**
Age 0 to 1	48(F); 43(M)	70 (F); 70 (M)	Yokohama reports 60% (Females), 52% (Males) for Crested Argus, AZA reports 35%(females), 34% (males) for Great Argus. Sample sizes are small for the Crested Argus. A mean of the two is used in the baseline models and an increased value is assumed for wild birds (no data available).
Age 1-2	15	15	15% from Crested Argus data, 12% from Great Argus.
Age 2+	5 - 25	5-25	Function 1: 5+(5*(A>9))+(15*(A>19)) – captive (both sexes). Function 2: 5+(5*(A>9)) – wild females. Function 3: 10+(5*(A>9)) – wild males (assumes more early deaths from competition).

% Males in breeding pool	100%	25%	All males have an opportunity to breed in captivity. In the wild it is assumed that competition increased opportunities for some males to dominate. No data available on the size of this effect.
Initial population size	100 ADULTS (50M;50F)	100 ADULTS (50M;50F)	In harvest models the captive population young are released, adults are retained and replaced as needed (with young)
Carrying capacity	100 ADULTS (50M;50F)	100 ADULTS (50M;50F)	Carrying capacity is set to 100 adult individuals for testing and verification.
Catastrophes	-	1 (Reed et al.)	Based on Reed et al – study of catastrophes across multiple species showed a 14% chance per generation of a population crash of 50%. Included here as 2% overall frequency, 50% survival in year of occurrence. No catastrophes included in the captive base model.

Captive Baseline Model Performance

With the model values described in Table 36, deterministic projections (i.e. without stochastic influences on reproduction and mortality rates) show a population that grows at an annual rate of approximately 8% per year (r =0.0786; λ =1.0818) and has a generational growth rate of Ro=1.8516. Generation time (T), is 7.84 years for both sexes. Stable age structure for this modelled population is illustrated in Figure 21.

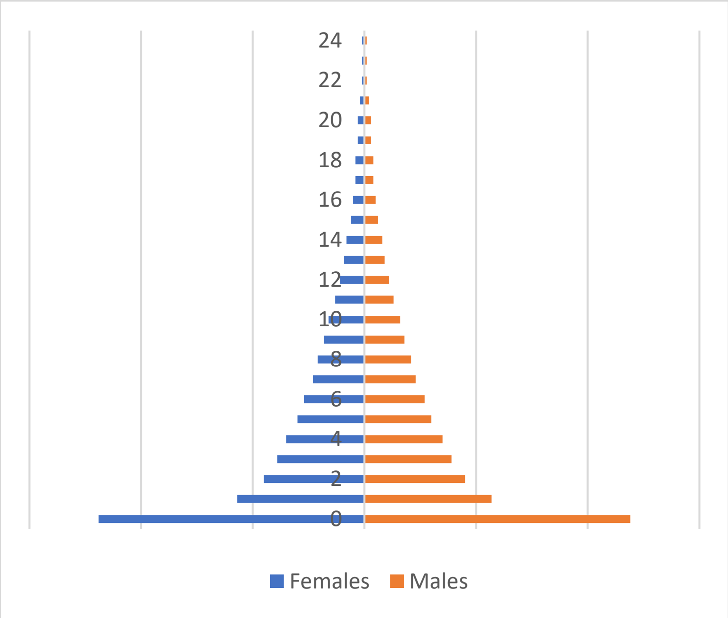


Figure 21. Age-pyramid portraying a stable-age structure for a captive population of Annamite Crested Argus, calculated through VORTEX. Proportions of males and females are shown on the X-axis; age-classes are shown on the Y-axis. Proportions of adults and juveniles are 0.762 and 0.238 respectively.

Including stochastic elements in the baseline model (i.e. inbreeding, demographic stochasticity and year-to-year environmental variation in age-specific vital rates) reduces the average growth rate from r=0.0786 to r=0.0710 and introduces considerable year-to-year variation into that rate (SD=0.0578). At the population size modelled (N=100) none of the simulated populations go extinct over the 50-year period and the population remains at or close to capacity throughout (N at 50 years=99.19). Gene Diversity retained at 50 years is GD=0.9342.

Wild Baseline Model Performance

Deterministic growth in the Wild Baseline Model is approximately 5% per year (r =0.0468; λ =1.0479). Introducing stochastic influences reduces average growth to r=0.0247 ± 0.1274. Most of this reduction can be attributed to the generic catastrophe that is introduced, which occurs probabilistically, approximately once every 50 years, reducing overall survival by 50% in the year of occurrence. Without this, stochastic growth is higher (r=0.0407 ± 0.0761). The inclusion of the catastrophe also reduces gene diversity at 50 years (from GD=0.9161 to 0.8942) and increases 50-year extinction risk slightly, from P(Ex)=0.0000 to 0.0040. A comparison of 50-year simulations for the two stochastic models is shown in Figure 22. below.

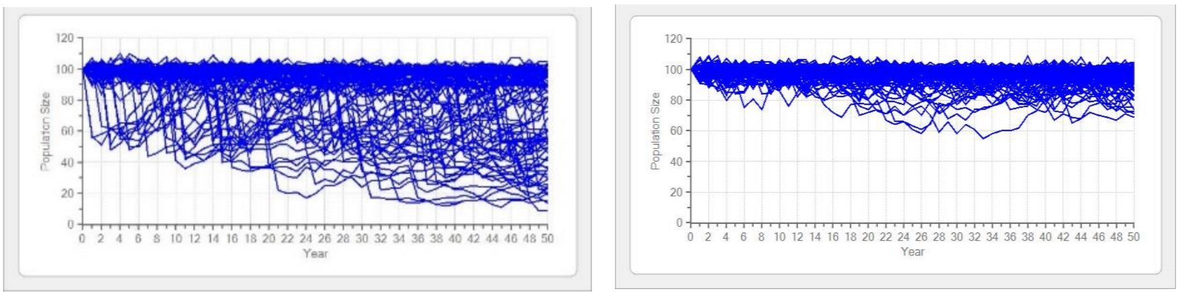


Figure 22. Comparison of two wild models for the Annamite Crested Argus. Left: with a once-in-50-year catastrophe that reduces overall survival by half in the year of occurrence. Right: the same model without this catastrophe. Starting population size = carrying capacity = 100 individuals, models are run for 100 years with 1000 iterations.

Table 36. Comparison of three Annamite Crested Argus Baseline Models: Vietnam captive, wild, and wild with a generic catastrophe included, showing 50-year mean growth rate (r), extinction risk (P(Ex)), gene diversity (GD) retention, and mean generation time (T).

Parameter - Mean ± SD	**Captive (VIET)**	**Wild**	**Wild (with catastrophe)**
Growth rate (r)	0.0710 ± 0.0578	0.0407 ±0.0761	0.0242 ± 0.1273
P(Ex) at 50 yrs	0.0000	0.0000	0.0040
GD at 50 yrs	0.9342	0.9161	0.8942
Mean Gen. Time (T) (yrs)	7.84	6.65	6.58

Sensitivity Testing

Using the Captive Baseline Model, each parameter in turn was varied across a range of values to explore which have the greatest impact on model performance (see Table 38). Those parameters with most influence should be targets either for further information gathering (where they are the subject of uncertainty) or for discussions about management intervention where this is considered feasible.

Table 37. Values used to test the sensitivity of the Annamite Crested Argus Baseline Model (captive population) to uncertainty or variation in individual parameters. Baseline values are in red.

Parameters (biology)	**Tested values**
Age First Offspring (f)	**1, 2, 3, 4, 5, 6**
Age First Offspring (m)	**1, 2, 3, 4, 5, 6**
Age Last Offspring (f)	**14, 16, 18, 20, 22, 24, 26**
Age Last Offspring (m)	**14, 16, 18, 20, 22, 24, 26**
Maximum Lifespan (m & f)	**16,18, 20, 22, 24, 26, 28**
% Breeding Females	**20, 30, 40, 50, 60, 70, 80**
Mean Offspring Number	**1, 1.47, 2, 3, 4**

Parameters (biology)	Tested values
Female Mort. Rates % [0;1]	**40, 42, 44, 46, 48, 50, 52, 54, 56**
Female Mort. Rates % [2;19]	**5, 6, 7, 7.5, 8, 9, 10**
Male Mort. Rates % [0;1]	**35, 37, 39, 41, 43, 45, 47, 49, 51**
Male Mort. Rates % [2;19]	**5, 6, 7, 7.5, 8, 9, 10**
Sex-Ratio (% male)	**30, 35, 40, 45, 50, 55, 60, 65, 70**

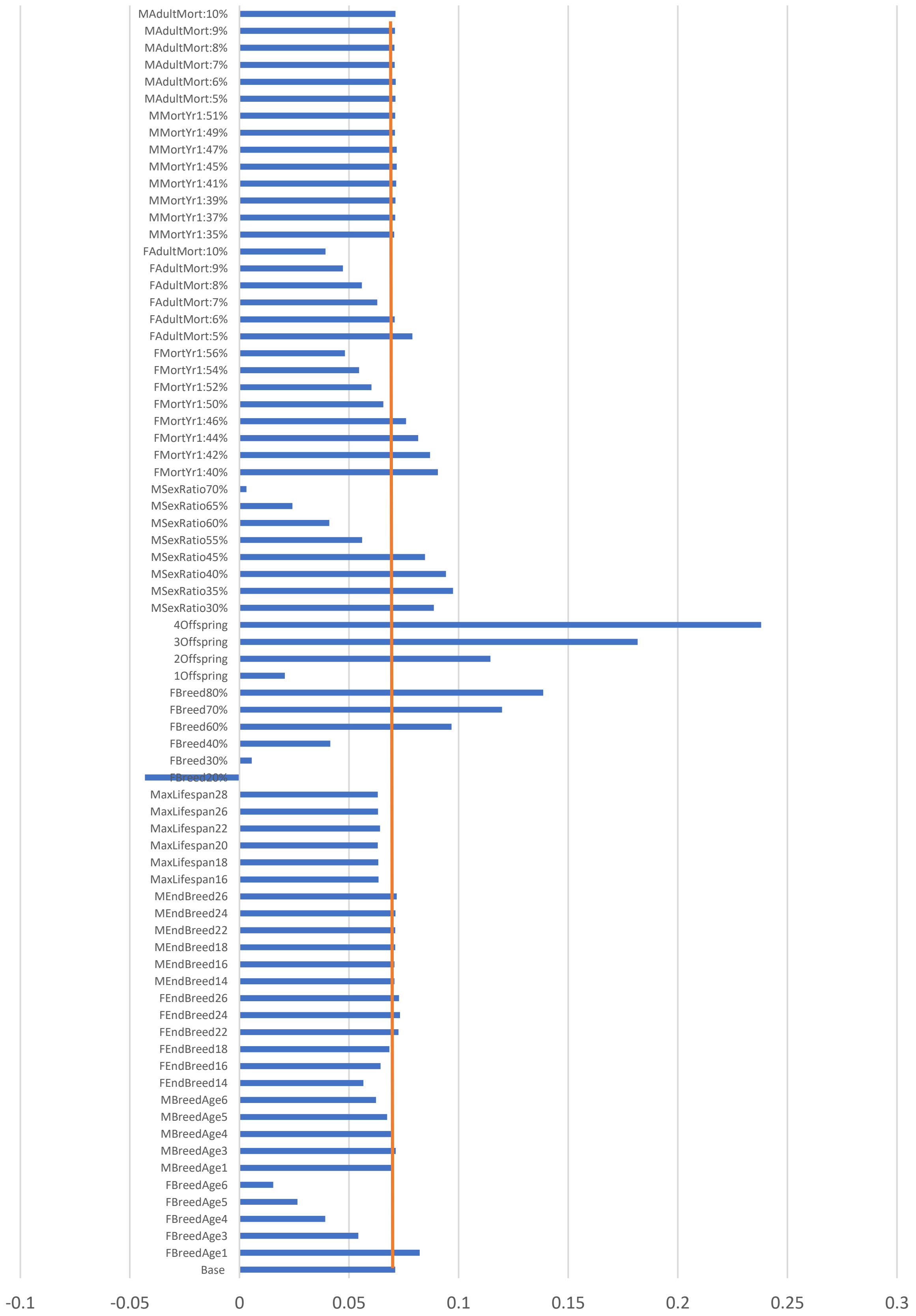
As illustrated in Figure 24, across the ranges of values tested, model growth is more sensitive to changes in some parameters than in others. Specifically, across the range of values tested:

Most influential parameters: number of offspring produced per clutch; percentage of females breeding each year; ratio of females to males in the population.

More influential parameters: age at first breeding for females; female mortality rates;

Less influential parameters: age at last breeding for females; age at first and last breeding for males; male mortality rates; .

Figure 24. Sensitivity Test Results: Mean Growth Rate (stoch-r)



Ex situ populations: founder number and carrying capacity

A viable *ex situ* population is defined here as one that shows:

- 50-year extinction risk ≤ 0.000;
- mean growth rate > 0.000
- 50-year gene diversity retention ≥ 90%.

In addition to the factors identified in the previous section, population viability is sensitive to the number of founder individuals and to the carrying capacity of the *ex situ* facilities. With too few individuals, chance factors (demographic and genetic) can have a disproportionately negative effect on population growth, in some cases resulting in declines to extinction. In addition, assuming all other things equal, starting gene diversity increases as founder number increases, and loss of gene diversity over time is slower in larger populations than in smaller ones. Therefore, we expect populations starting with more founders and growing to larger carrying capacities to be more viable. As managers may have only partial influence over founder number and carrying capacity, a series of models were run to explore the trade-offs between them. Founder number was varied from Ni=10-30 individuals, at increments of 2; carrying capacity was varied from K=30-100 individuals, at increments of 10. The results are illustrated in Table 39 below.

Note that initial population size and founder number are used interchangeably here though they are not the same. Founders are usually considered to be individuals that are not (recently) related to each other. In general, starting a population with unrelated individuals should provide better genetic outcomes (the amount of gene diversity captured should be higher and the rate of accumulation of inbreeding lower). This is not always possible in practice and starting populations may include close relatives. In the models, the starting individuals are unrelated and so are equivalent to founders. Also, in these models, carrying capacity represents the total number of individuals (adults and juveniles) that can be held. This should not be confused with scenarios set for other species in the wider PVA project, in which carrying capacity refers to adult holdings only

As illustrated in Table 39, the viability criterion for average population growth (stoch-r > 0.000) is met in all the scenarios tested. The extinction risk criterion (P(Ex)>0.000) requires a founder base of at least Ni=20 birds (at even sex-ratio) combined with a carrying capacity of at least K=70. However, at a founder base of Ni=16 and K=30, extinction risk drops below 1% and the difference beyond that point between a positive extinction risk and one of zero is likely to arise through chance alone. For this reason extinction risk values that sit between these thresholds are shaded yellow. The gene diversity threshold (GD ≥ 0.90) is met only after the number of founders exceeds Ni=24 and carrying capacity is at least K=100. Note that these are 50-year iterations and shorter programme length would allow the gene diversity target to be met with fewer founders or with reduced capacity. The models can be used in future to test additional scenarios as needed.

Table 38. Impact of starting population size (Ni) and carrying capacity (K) on population performance indicators over 50 years: r=growth; P(Ex)=extinction risk; GD= gene diversity. Orange=does not meet viability criteria; Green=meets viability criteria; Yellow=almost meets extinction risk criterion.

	K=30	K=40	K=50	K=60	K=70	K=80	K=90	K=100
	r=0.045	r=0.0459	r=0.0474	r=0.0484	r=0.0502	r=0.0487	r=0.0483	r=0.0487
Ni=10	P(Ex)=0.046	P(Ex)=0.071	P(Ex)=0.07	P(Ex)=0.052	P(Ex)=0.051	P(Ex)=0.06	P(Ex)=0.066	P(Ex)=0.069
	GD=0.7425	GD=0.7709	GD=0.7812	GD=0.7877	GD=0.7885	GD=0.7956	GD=0.796	GD=0.7991
	r=0.0474	r=0.0512	r=0.0524	r=0.0536	r=0.0535	r=0.0528	r=0.0536	r=0.0534
Ni=12	P(Ex)=0.035	P(Ex)=0.029	P(Ex)=0.016	P(Ex)=0.019	P(Ex)=0.03	P(Ex)=0.034	P(Ex)=0.034	P(Ex)=0.028
	GD=0.7644	GD=0.7947	GD=0.8063	GD=0.8144	GD=0.8236	GD=0.8257	GD=0.8255	GD=0.8307
	r=0.0501	r=0.0529	r=0.0546	r=0.0565	r=0.0569	r=0.0579	r=0.0557	r=0.0571
Ni=14	P(Ex)=0.011	P(Ex)=0.013	P(Ex)=0.015	P(Ex)=0.014	P(Ex)=0.012	P(Ex)=0.01	P(Ex)=0.016	P(Ex)=0.012
	GD=0.7781	GD=0.8089	GD=0.8238	GD=0.8389	GD=0.8435	GD=0.8484	GD=0.845	GD=0.851
	r=0.0536	r=0.0563	r=0.0576	r=0.0576	r=0.0588	r=0.0602	r=0.0587	r=0.0612
Ni=16	P(Ex)=0.009	P(Ex)=0.006	P(Ex)=0.005	P(Ex)=0.006	P(Ex)=0.005	P(Ex)=0.005	P(Ex)=0.012	P(Ex)=0.005
	GD=0.7881	GD=0.8183	GD=0.8352	GD=0.8471	GD=0.8557	GD=0.8616	GD=0.8642	GD=0.8703
	r=0.0532	r=0.0584	r=0.0591	r=0.0601	r=0.0619	r=0.061	r=0.0621	r=0.0616
Ni=18	P(Ex)=0.008	P(Ex)=0.003	P(Ex)=0.004	P(Ex)=0.004	P(Ex)=0.003	P(Ex)=0.003	P(Ex)=0.003	P(Ex)=0.004
	GD=0.7929	GD=0.8265	GD=0.8469	GD=0.8579	GD=0.8695	GD=0.8717	GD=0.8785	GD=0.8804
	r=0.0539	r=0.0583	r=0.0598	r=0.0618	r=0.0624	r=0.064	r=0.0639	r=0.0642
Ni=20	P(Ex)=0.005	P(Ex)=0.002	P(Ex)=0.003	P(Ex)=0.001	P(Ex)=0	P(Ex)=0.001	P(Ex)=0.002	P(Ex)=0.001
	GD=0.7948	GD=0.8345	GD=0.8548	GD=0.8679	GD=0.8763	GD=0.8827	GD=0.8874	GD=0.8912
	r=0.054	r=0.0584	r=0.0602	r=0.0618	r=0.0634	r=0.0638	r=0.064	r=0.0649
Ni=22	P(Ex)=0.006	P(Ex)=0.003	P(Ex)=0	P(Ex) 0.001	P(Ex)=0.001	P(Ex)=0	P(Ex)=0.002	P(Ex)=0.001
	GD=0.7983	GD=0.8334	GD=0.8573	GD=0.8732	GD=0.8813	GD=0.8887	GD=0.8922	GD=0.8971
	r=0.0529	r=0.0591	r=0.0616	r=0.0632	r=0.0642	r=0.0654	r=0.0652	r=0.0653
Ni=24	P(Ex)=0.004	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0.001	P(Ex)=0	P(Ex)=0
	GD=0.7966	GD=0.8401	GD=0.8632	GD=0.8757	GD=0.8848	GD=0.8927	GD=0.8988	GD=0.9013
	r=0.0538	r=0.0593	r=0.0621	r=0.0642	r=0.0649	r=0.0653	r=0.0665	r=0.066
Ni=26	P(Ex)=0.003	P(Ex)=0.001	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0.001
	GD=0.8004	GD=0.8429	GD=0.8657	GD=0.8805	GD=0.8905	GD=0.8964	GD=0.9027	GD=0.907
	r=0.0537	r=0.0597	r=0.0629	r=0.0643	r=0.0661	r=0.0661	r=0.0666	r=0.067
Ni=28	P(Ex)=0.005	P(Ex)=0	P(Ex)=0	P(Ex) = 0	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0
	GD=0.8017	GD=0.8431	GD=0.8676	GD=0.8826	GD=0.8934	GD=0.8998	GD=0.9071	GD=0.9113
	r=0.0552	r=0.0598	r=0.0632	r=0.0649	r=0.0651	r=0.0668	r=0.0669	r=0.0675
Ni=30	P(Ex)=0.002	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0	P(Ex)=0
	GD=0.8016	GD=0.8436	GD=0.8701	GD=0.8846	GD=0.8958	GD=0.9046	GD=0.9093	GD=0.9146

How quickly can releases begin?

With current estimated values, a population beginning with 24 founder individuals would be expected to reach a capacity of 100 individuals after approximately 40 years. However, the modelled iterations show highly variable results (see Figure 24.) with some populations reaching capacity before 15 years.

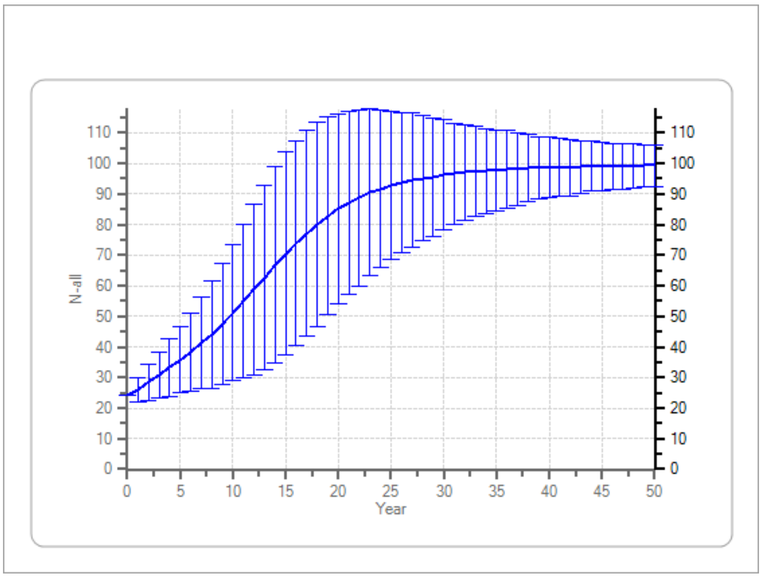


Figure 24. Mean population size over time for the modelled Annamite Crested Argus captive population with 24 founders and K=100, showing 90% of the distribution of values (1000 iterations).

Releases can begin before capacity is reached but if they begin too early, or if too many individuals are extracted at each release event, the viability of the population may be compromised.

Potential release strategies have not yet been discussed for this species and it might be more useful to hold such discussions once there is more certainty about what can be achieved in the proposed Vietnam facility. As an entry point to discussions, a series of models were constructed to look at the trade-offs between how many animals are released each year and when those annual releases begin. In these models, releases are annual and of either 4, 6 or 8 individuals (all aged 1-2 years with an even sex-ratio), and the first year of release is varied from Year 5 to Year 30, at five-yearly intervals. All populations begin with 24 founders and a carrying capacity K=100 (which at stable-age structure typically includes approximately 75 adults and 25 offspring). The results are shown in Table 40. As expected, beginning releases in later years (when the population is larger) and harvesting fewer animals for release, reduces extinction risk and increases gene diversity over the 50-year period. Releasing after year 25 and only four individuals per year are the only scenarios that come close to achieving the viability definition described (though extinction risk is not zero as specified, it is close to it at 1-2%). These results are based on Baseline Model values

Table 39. Impact of starting year of releases, number of birds released, and population performance indicators (r=growth; P(Ex)=extinction risk; GD=gene diversity).

Annual release number	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30
	r=-0.0487	r=-0.0086	r=0.0183	r=0.0312	r=0.0419	r=0.0462
N=4	P(Ex)=0.852	P(Ex)=0.435	P(Ex)=0.186	P(Ex)=0.079	P(Ex)=0.022	P(Ex)=0.01
	GD=0.8588	GD=0.8773	GD=0.8957	GD=0.8992	GD=0.9038	GD=0.9019
	r=-0.0761	r=-0.0434	r=-0.0146	r=0.0077	r=-0.025	r=0.0362
N=6	P(Ex)=0.99	P(Ex)=0.832	P(Ex)=0.466	P(Ex)=0.18	P(Ex)=0.485	P(Ex)=0.013
	GD=0.8361	GD=0.873	GD=0.8847	GD=0.8896	GD=0.8916	GD=0.9034
	r=-0.0859	r=-0.0606	r=-0.0377	r=-0.0165	r=0.0027	r=0.0214
N=8	P(Ex)=1	P(Ex)=0.968	P(Ex)=0.748	P(Ex)=0.381	P(Ex)=0.132	P(Ex)=0.033
	GD=0	GD=0.8244	GD=0.8664	GD=0.8717	GD=0.8853	GD=0.8973

Summary

- The Crested Argus Pheasant models are most sensitive to offspring number and to the proportion of females breeding each year. More certainty around these parameter estimates would increase the value of the models in predicting likely performance.
- The models grow consistently towards carrying capacity and can generate a harvest for release. Delaying releases until the population reaches a carrying capacity of around 100 birds allows consistently larger harvests. Reaching this number can take 15-40 years depending on the success of the program. Good husbandry from the outset is critical, as for the other species. Improvements in survival and breeding rates through good husbandry will allow harvests to be larger and begin earlier.
- More information and discussion are needed to work through these initial results and determine whether they adequately represent Crested Argus Pheasant potential in the proposed programme. Models can be refined and re-run once this is done.

BOURRET'S BOX TURTLE

Introduction

Bourret's Box Turtle (*Curora bourreti*) is also known locally as the Central Vietnamese Flowerback Box Turtle and the Indochinese Box Turtle. It is mainly terrestrial and inhabits moist, closed-canopy evergreen forest, usually between 300-700m altitude. It is a medium-sized turtle (adult carapace reaches 19-20 cm). Threats are primarily from poaching and trading for the Chinese food and medicine markets, despite its listing on CITES Appendix I. Habitat destruction from logging and the creation of new farmland may also be a threat to remaining populations. The species is held in captivity but is considered easily stressed there. Successful breeding is rare but slowly increasing. Wild population estimates range from 10,000–20,000 and the species is currently categorised as Critically Endangered (IUCN 2018). The current plan for *C. bourreti*, is to establish an *ex-situ* population using adult confiscated turtles and to use this to generate animals for release to prepared sites.

Captive Baseline Model

The Captive Baseline Model was constructed to emulate the dynamics of a captive population in Vietnam under achievable conditions. It was built using captive data from similar turtle species, estimates where no data were available, and information about the intended management of the captive population, which is not yet established. All information was provided by Peter Paul van Dijk. Captive Baseline Model parameters are described in Table 42. The performance of the models is described below.

Deterministic rates	
Lambda (λ)	1.19
Generational growth (Ro)	11.71
Generation time (T)	14.14

Table 40. Deterministic outputs for the Captive Baseline Model for Bourret's Box Turtle, showing annual (λ) and generational (Ro) growth rates, and generation length (T).

Deterministic projections (i.e., without stochastic influences on reproduction and mortality rates) show a population that grows at an annual rate of 19% (λ =1.19). Modelled generation time (for both sexes) is approximately 14 years. With stochastic elements included, growth remains strongly positive, with an instantaneous growth rate of r=0.22 and no risk of extinction over the 50-year period, even from the small starting population size considered (N=12). Gene diversity at year 50 is 87%, which is below the recommended thresholds often applied to *ex situ* programmes (90 - 95%) (Frankham et al. 2002). See Table 42 and Figure 25.

Stochastic rates	
Instantaneous Growth Rate (r)	0.22±0.129
Gene Diversity (GD) at 50 yrs	87±0.03%
Extinction Risk (P(Ex))	0.00
N (All)	40.0±2.61

Table 41. Captive Baseline Model for *Cuora bourreti*: 50 year results (500 iterations).

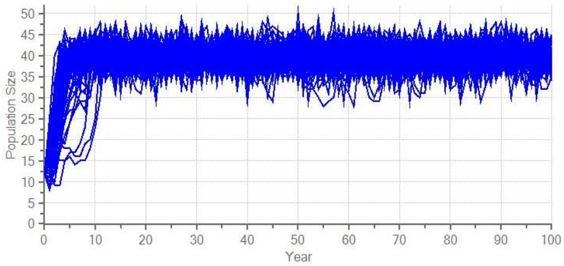


Figure 25. Captive Baseline Model for *Cuora bourreti*: changes in population size over a 100-year timeframe, with carrying capacity capped at 50 individuals (100 iterations).

The Captive Baseline Model is initiated with 12 adults (8 females, 4 males) and throughout the simulations the sex-ratio at birth is maintained at two females for each male, which is to be achieved in practice through artificial manipulation at the egg stage. Carrying capacity of the captive environment is set to 50 individuals. Where the population exceeds this size at the end of a run, additional mortality is imposed, randomly across age classes, to keep the population roughly within the boundary set. The model is constructed in this way for the purpose of initial testing and verification and does not represent intended management in the Vietnam facility – this is covered later, in a range of scenarios. The Captive Baseline Model age structure stabilises at approximately 20 adults and 30 juveniles, (see Figure 26. below). The increase in the number of adults after 7 years reflects the time taken for the first juvenile cohort to reach maturity.

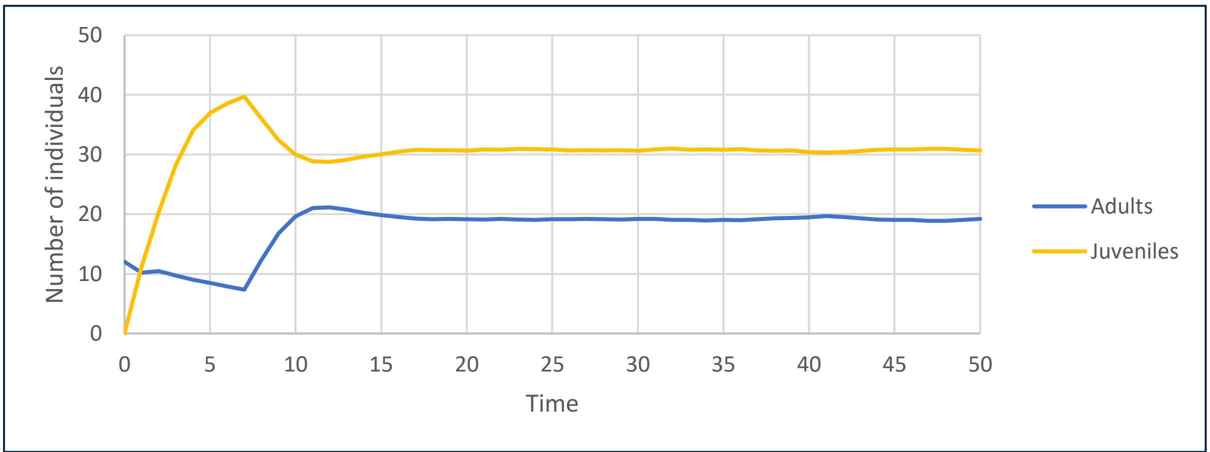


Figure 26. Ratio of adults to juveniles in the Captive Baseline Model for *Cuora bourreti* (500 iterations).

Table 42. Captive Baseline Model Parameters for Bourret's Box Turtle, *Cuora bourreti* with associated rationale.

VORTEX Parameter	Captive Value	Wild Value	Details (from P. P. van Dijk unless otherwise indicated)
Period modelled (years)	100	100 years	Long-lived species: shorter timeframes are insufficient for illustrating inter-generational effects.
Inbreeding depression severity	3.14 Lethal Equivalents	6.29 Lethal Equivalents	Inbreeding in wild turtles is demonstrated (Gallego-Garcia et al 2018) but impact on fitness poorly studied. Both positive and negative effects have been suggested (Philips et al. 2017). VORTEX defaults used as a precaution, based on studies across multiple species (for captive: Ralls & Ballou (1988); for wild: O'Grady et al (2006)).
Percent due to recessive alleles	50%	50%	Default based on studies of a limited number of species.
EV correlation: reproduction and survival	None	None	Factors affecting the two are not coupled in these turtles (Dijk, pers. comm.).
Breeding system	Polygynous	Polygynous	Both sexes can breed with multiple mates in a season. In the model males can breed with > 1 female.
Age of first offspring	7	7	Both sexes. New female recruits may take 2 or more years to acclimatise to captivity before breeding successfully. This may depend on where they are acquired from. This element is not included in the models.
Max. age of reproduction	50 years	50 years	Assumes both sexes breed throughout life. Data from other taxa suggest older females make the greatest contribution (laying larger clutches and in optimal conditions). No data to base estimates of the size of this effect on. Not included in the Baseline Model.
Maximum lifespan	50	50	Both sexes typically live 20-50 years. Life can extend beyond this but rarely.
Maximum number of clutches per year	2	2	50% will produce a second clutch (but no data on clutch sizes or relative survival of first and second clutches).
Maximum number of progeny per clutch	4	4	Average of 1.52 hatchlings per clutch (S.D. 0.72) (sample size unknown).
Sex-ratio at birth in % males	33%	50%	Natural ratio = 50% (assumed). Clutches will be incubated and ratio manipulated towards 33% males.
% adult females breeding (S.D)	90% (5%)	90% (5%)	Estimated range 80-100%. All females are expected to breed in most years (assumed to ramp up from 30-90% over 3 years due to gradual husbandry improvements – though not included in baseline models).
Distribution of offspring number:			Taken from studbook data (note this is hatchlings, not eggs).
1 Offspring	58.2%	58.2%	
2 Offspring	34%	34%	
3 offspring	5%	5%	
4 offspring	2.8%	2.8%	

VORTEX Parameter	Captive Value	Wild Value	Details (from P. P. van Dijk unless otherwise indicated)
Female & Male mortality rates			SD in mortality due to EV set to 5% of mean in each age-class
Age 0 to 1 yr	25%	85%	Estimated by Peter Paul van Dijk.
Age 1 to 2 yrs	10%	50%	
After age 2 yrs	5%	20%	3-5 yrs=15%; 5-6=10%; 6-8=5%; 8+=2%
After age 40 yrs	25%	25%	
% Males in breeding pool	100%	100%	All males can breed and will have the opportunity to do so.
Initial population size	12 ADULTS	varied	Four males, 8 females: starting point for testing the limits of viability.
Carrying capacity	50	varied	Carrying capacity is set to 50 individuals in the Baseline, for testing and verification.
Catastrophes	Theft	varied	Incursion frequ.=5%; 40% of adults are removed.

Sensitivity Testing

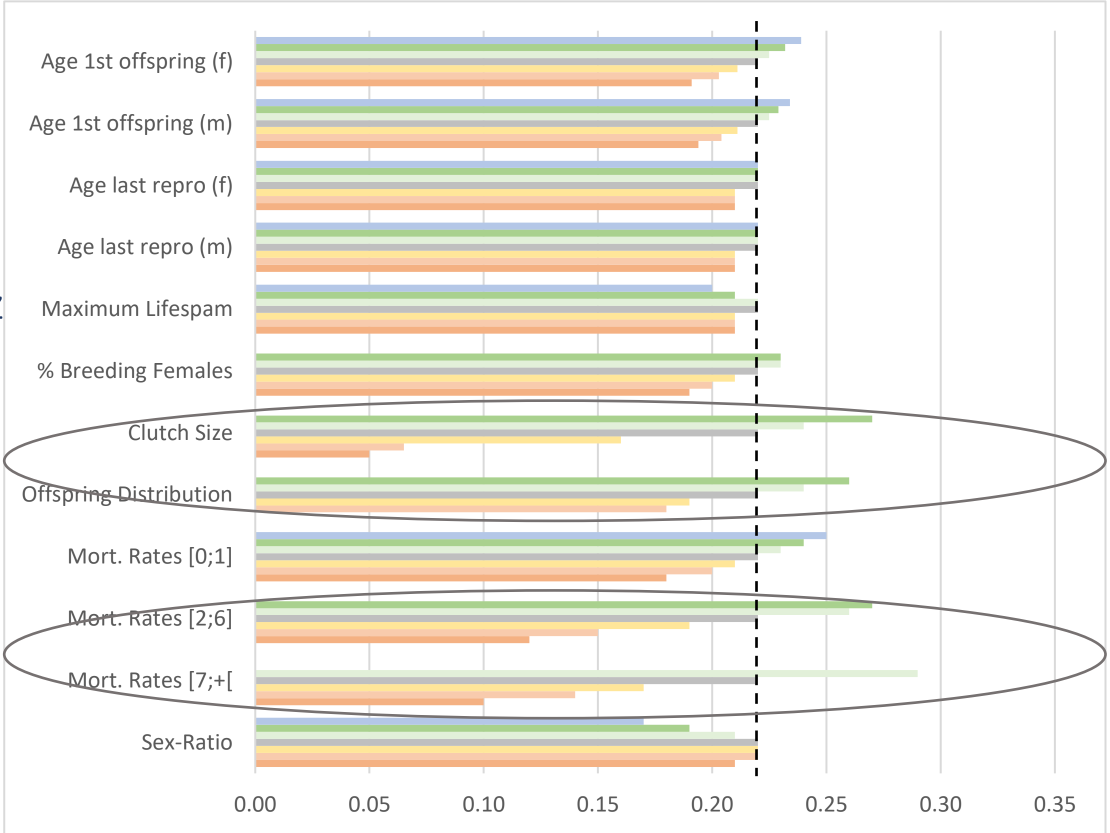
There is parameter uncertainty in the Baseline Model. Each parameter in turn was varied across a plausible range of values to explore which elements of uncertainty have the greatest impact on model performance. The values used are shown in Table 43. Results are summarised in Figure 27. Note that for the purpose of sensitivity testing, nesting females can have 2, 1 or zero clutches per year, and mortality is separated into three stages: neonates (0 to 1 year-old); juveniles (2 to 6 years-old) and adults (7 years-old and above).

Table 43. Values used in testing the sensitivity of the Captive Baseline Model to variation in specific parameters.

BIOLOGY		Extreme negative	Very Negative	Negative	Base Value	Positive	Very Positive	Extreme Positive
Age 1st offspring (f)		10	9	8	7	6	5	4
Age 1st offspring (m)		10	9	8	7	6	5	4
Age last repro (f)		35	40	45	50	55	60	65
Age last repro (m)		35	40	45	50	55	60	65
Maximum lifespan		35	40	45	50	55	60	65
% Breeding females		75	80	85	90	95	100	-
Clutch distribution per year (0/1/2)		75/25/0	50/50/0	25/50/25	0/50/50	0/25/75	0/0/100	-
Offspring distribution per clutch (1/2/3/4)		-	78/22/0/0	68/30/2/0	58/34/5/3	48/38/8/6	38/42/11/9	-
Mort. rates [1st year]	Age 0-1	40%	35%	30%	25%	20%	15%	10%
Mort. rates [juvenile]	Age 2	20%	15%	10%	5%	0%	0%	-
	Age 3 6	25%	20%	15%	10%	5%	0%	-
Mort. rates [adults]	Age 7+	25%	20%	10%	5%	0%	-	-
Sex-ratio		48%	43%	38%	33%	28%	23%	18%

Figure 27. illustrates the results of the sensitivity tests. The dotted line indicates the Baseline Model value. As shown, across the range of values modelled, **clutch size and post-first-year mortality rates (juveniles and adults)** have the biggest impact on Baseline Model performance. Resolving uncertainty in these parameters would contribute significantly to the predictive value of the models.

Figure 27. Sensitivity tests for the *Cuora bourreti* Captive Baseline Model showing the impact on population growth rate (r), of varying parameters across a plausible range of values (values shown in Table 44). Dashed lines represent outputs for the baseline model (in grey). The most sensitive parameters are circled.



Wild population models

Table 44 shows a comparison of captive and wild population performance with wild parameters as described in Table 42. An additional wild model is also presented, with more optimistic mortality rates.

Table 44. Comparison of captive and wild population performance. For this illustration, all three populations were initiated with 50 individuals and allowed to grow to N=250. There is no translocation between the populations and the captive population is not supplemented. Shown are: stochastic growth rate (r), risk of extinction by year 50, and average values at year 50 for gene diversity and population size (500 iterations).

Stochastic rates	Captive	Wild	Wild (optimistic)
Instantaneous growth rate (r)	0.24 ± 0.07	0.01 ± 0.08	0.023 ± 0.06
Gene Diversity (GD) at 50 yrs	0.94 ± 0.01	0.77 ± 0.12	0.96 ± 0.01
Extinction Risk (P(Ex))	0%	0%	0%
N (Ext)	250.1 ± 7.09	181.05 ± 55.82	250.1 ± 6.85
N (All)	250.1 ± 7.09	181.05 ± 55.82	250.1 ± 6.85

Figure 28. Age-pyramid portraying the stable-age structure of female turtles in a captive population (left) and in a wild population (right). Numbers of females are shown on the X-axis; age-classes are shown in square brackets on the Y-axis.

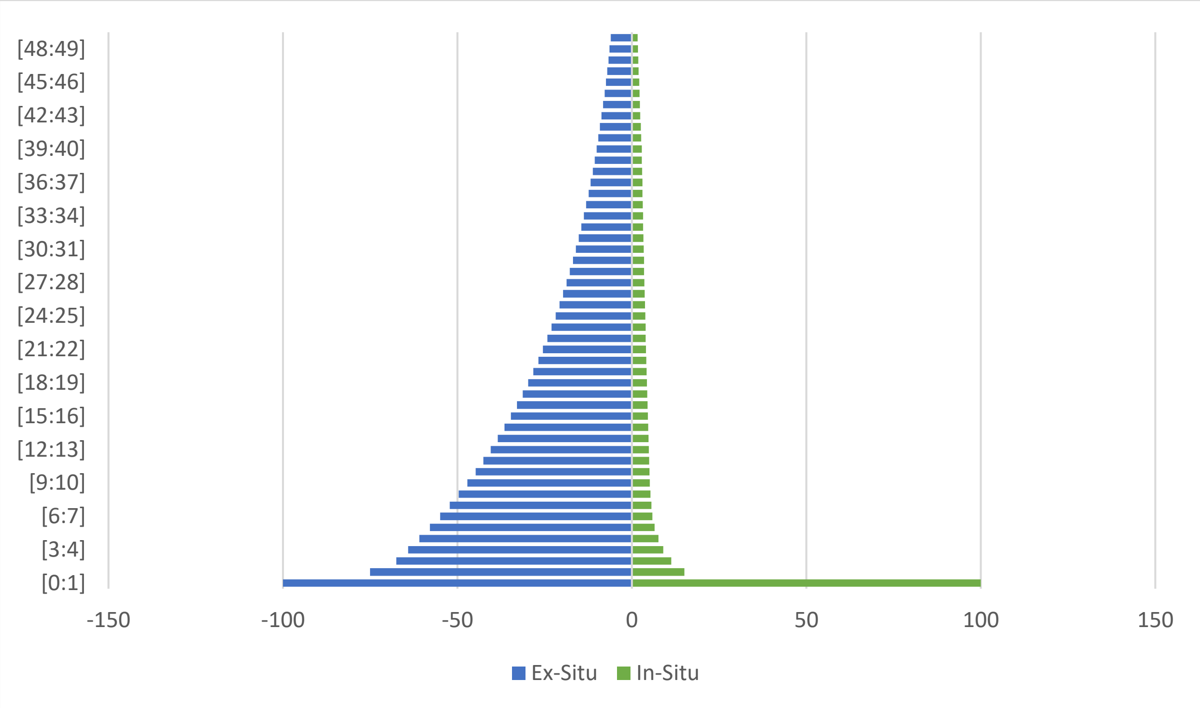


Figure 28 illustrates the differences in age-structure between the captive and wild baseline models. As can be seen by both Table 45 and Figure 28., the wild models (even the more optimistic one) show significantly less growth potential than the captive model due to the greatly increased mortality rates in the early stages.

For management scenario testing, additional risks were added to the wild population models to reflect potential environmental risks over and above year-to-year age-specific mortality. Some of these threats may be common to all sites and some may be specific to individual sites. Threats common to more than one site may operate at different frequencies or severities, depending on the site. All threats potentially affecting wild populations and applied in one or more of the scenarios are described in Table 45 below.

Table 45. Threats included in the Wild Models for the purpose of scenario testing. Estimated by Peter Paul van Dijk.

Threat 1.	
Description of threat	Extreme weather: direct hit of the site by a typhoon
Description of how it affects turtles	Directly, not greatly affected: a few may get washed away, a few may be crushed under a falling tree or rockfall;
Frequency of occurrence	Once in 80-200 years per site.
Scale of occurrence	Would affect all populations within 100 km of strike zone, not beyond that
Impact on normal mortality	Double the normal annual mortality rate
Impact on normal reproduction	Worst case scenario: half of all nests flooded/lost (though in reality, probably not significant)
Other impacts	The hard-to-gauge impact is how nearby humans are affected and how they respond; having potentially lost their crops and livestock,

	and with relief slow to come, they may turn to subsistence foraging, and a breakdown of protected area governance may occur.
Threat 2.	
Description of threat	Extreme weather: weak or failing monsoon leading to forest fires
Description of how it affects turtles	Leaflitter fire will burn and kill, or maim, most animals residing in the burned area
Frequency of occurrence	Uncommon to never in evergreen forest areas, once in 80 years per site (natural frequency) or more (annual in some anthropogenic regions) in deciduous forest types
Scale of occurrence	Localised – one entire site at worst, likely only partial
Impact on normal mortality	Local mortality in burn area increases to 50-100% of all age classes (50+% of adults, 80-100% of subadults, juveniles & hatchlings, also due to exposure and predation in the weeks after fire events)
Impact on normal reproduction	Assume no reproduction in the next reproductive season (females are recovering from burn injuries and lack of food and shelter)
Threat 3.	
Description of threat	Disease outbreak among turtles (Ranavirus, Mycoplasma, Intranuclear coccidiosis or similar)
Description of how it affects turtles.	Depends on disease and turtles' resistance; in extreme cases (ranavirus) can go from healthy-looking animal to dead in 3-5 days. Mycoplasma and coccidiosis would entail a long slow loss of condition and vigour.
Frequency of occurrence	Once in a century at any site.
scale of occurrence	Localised – one site at a time, likely only partial, unlikely to 'jump' to another population unless carried by humans (i.e., researchers etc. must adhere to sanitary and biosecurity measures)
Impact on normal mortality	Depending on disease and virulence, could be 90% or more mortality across all age classes.
Iimpact on normal reproduction	Unknown (assume females skip one reproductive season if affected and recovered)
Threat 4.	
Description of threat or catastrophe	Governance / social agreement breakdown: resumption of poaching
Description of how it affects turtles	Any turtle encountered will be extracted and lost from the wild population. Encounter rates can be high when using trained dogs.
Frequency of occurrence	Hopefully never at our project sites, but for statistical purposes call it once in 40 to 200 years per site. It would not last for 12 months, but given how small our re-intro sites will be, they can be hit hard in just a few weeks
Scale of occurrence	Could hit any of the sites, more or less independent of whatever happens at other sites.
Impact on normal mortality	Population loss can amount to 50% of all adults and 33% of juveniles in one year (33% juveniles because juveniles are harder to find, even for dogs, and tiny juveniles have so little value in trade that they may be detected but not collected)
Impact on normal reproduction	Unaffected (except by the reduced number of females)

Scenario Testing

The current plan for *Cuora bourreti*, is to establish an *ex-situ* population using adult confiscated turtles and to use this to generate animals for release to prepared wild sites, of which four are planned so far. Establishing the captive population should be possible because the species is so often found in trade. Adult founders that die will be replaced with further confiscated turtles or, if unavailable, with individuals from *ex-situ* populations in Europe or North America. *Ex-situ* spaces for this species will be limited because space is required for several other species that are less readily obtained from trade or from regional zoo programmes and so will require larger captive populations to retain gene diversity and ensure persistence.

Two of the challenges for this initiative are:

1) To minimise the captive space used by *Cuora bourreti* (so that more is available for other taxa) while at the same time holding enough animals to allow for a successful re-introduction programme.
2) To install a release strategy that balances the estimated costs and benefits of increasing the period of captive rearing (see below for further details).

Models were built to explore a range of management and release scenarios, to help identify successful strategies. These are described below. All management strategies were conceived by Peter Paul van Dijk.

Scenario 1. Initial management and release strategy

Scenario 1 describes the favoured option for managing the captive population and the associated release program:

- A captive founder group of 12 unrelated adult turtles (4 males, 8 females) is in place on Year 1.
- The number of adult turtles in the *ex-situ* facility remains at 12 (4 males, 8 females) throughout the program, maintained by:
    - staged releases of all turtles bred (see below);
    - replacement of adults lost (through death or theft) with unrelated adults of the same sex, accessed either from trade confiscations or from *ex situ* facilities in Europe or the USA.
- Expected rates of breeding success are achieved by Year 3 (with a linear increase to that rate from Year 1).
- Staged releases begin in Year 2 (following first successful captive breeding).
- Incursions by thieves can occur in the *ex-situ* facility. Thieves will only target adult breeders (that are valuable for their shells). Incursions are likely to happen once every 20 years and 30-50% of adults may be removed
- Turtles are assumed to be released at more than one wild site (so far, 4 are planned). To keep models simple, only one of them is modelled in this scenario.
- Survival of turtles in the wild is expected to vary as follows:
    - larger turtles should survive better than smaller ones (and we assume that size is closely correlated with age);
    - for turtles of equivalent size, those that have spent less of their rearing time in captivity are expected to survive better;
    - turtles reared in captivity show a severe mortality rate in the year of release (due to difficulties adjusting to natural habitat, weather, food, and because of poorer predator avoidance and defensive responses) but will show similar mortality rates to wild-born animals after that initial year.

A trade-off is therefore expected between releasing turtles when very young (when wild survival is always low, but the individuals are less affected by captive rearing/imprinting) versus releasing turtles when they are older/larger (when wild survival should be higher but may be reduced by the influence of captive rearing). A staged release strategy is therefore envisioned as described below, to take account of these competing challenges.

Scenario 1 includes releasing a mix of ages. The estimated mortality rates proposed are informed guesses, to be refined with data as the project progresses. Tables 46 and 47 below show the values used. Essentially, for captive-bred turtles of two-years and above, 50% of each juvenile age-class is released each year, with 100% of the final juvenile age-class released to avoid retaining any adult turtles except for the initial founders and their unrelated replacements. Released turtles exhibit translocation-associated mortality rates that vary with age and that are confined to the year of release. Thereafter, survivors assume the mortality rates of wild-born turtles.

Table 46. The percentage of the standing population in each age-class to be released from the *ex-situ* population, in each year of the programme's first decade (for Scenario 1). Note that "Project Year 1" is defined as the first year of successful breeding at the Bach Ma facility – animals may arrive before that, but this is not included in the models. If the founder stock are habituated animals from Cuc Phuong, some breeding may occur in the year following arrival, but this is less likely if they are fresh trade-confiscates. By Project Year 3, reproductive success is maximised.

	AGE OF ANIMALS RELEASED					
PROJECT YEAR	2 yr-olds	3 yr-olds	4 yr-olds	5 yr-olds	6 yr-olds	7 yr-olds
1*	0%	0%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%	0%
3	50%	0%	0%	0%	0%	0%
4	50%	50%	0%	0%	0%	0%
5	50%	50%	50%	0%	0%	0%
6	50%	50%	50%	50%	0%	0%
7	50%	50%	50%	50%	50%	0%
8	50%	50%	50%	50%	50%	100%
9	50%	50%	50%	50%	50%	100%
10	50%	50%	50%	50%	50%	100%

Table 47. The age-specific mortality estimated for released turtles, considering the influences of size and rearing time *ex situ,* compared to that estimated for wild turtles or those held solely *ex situ.* Note that the % annual mortalities shown assume negligible incidence of poaching or catastrophic impacts, and relate to 'normal' weather and seasonality, and predation and competition impacts from a reasonably intact and natural community of native species.

AGE CLASS	*CAPTIVE* MORTALITY	*BEST GUESS WILD* MORTALITY	*OPTIMISTIC WILD* MORTALITY	RELEASE-YEAR MORTALITY FOR REINTRODUCED TURTLES*
0-1	25%	85%	50%	Not applicable - no releases
1-2	10%	50%	15%	Not applicable - no releases
2-3	5%	20%	5%	50%
3-4	5%	15%	5%	40%
4-5	5%	15%	5%	30%
5-6	5%	10%	5%	20%
6-7	5%	5%	5%	20%
7-8	5%	5%	5%	10%
8+	5%	2%	2%	Not applicable - no releases

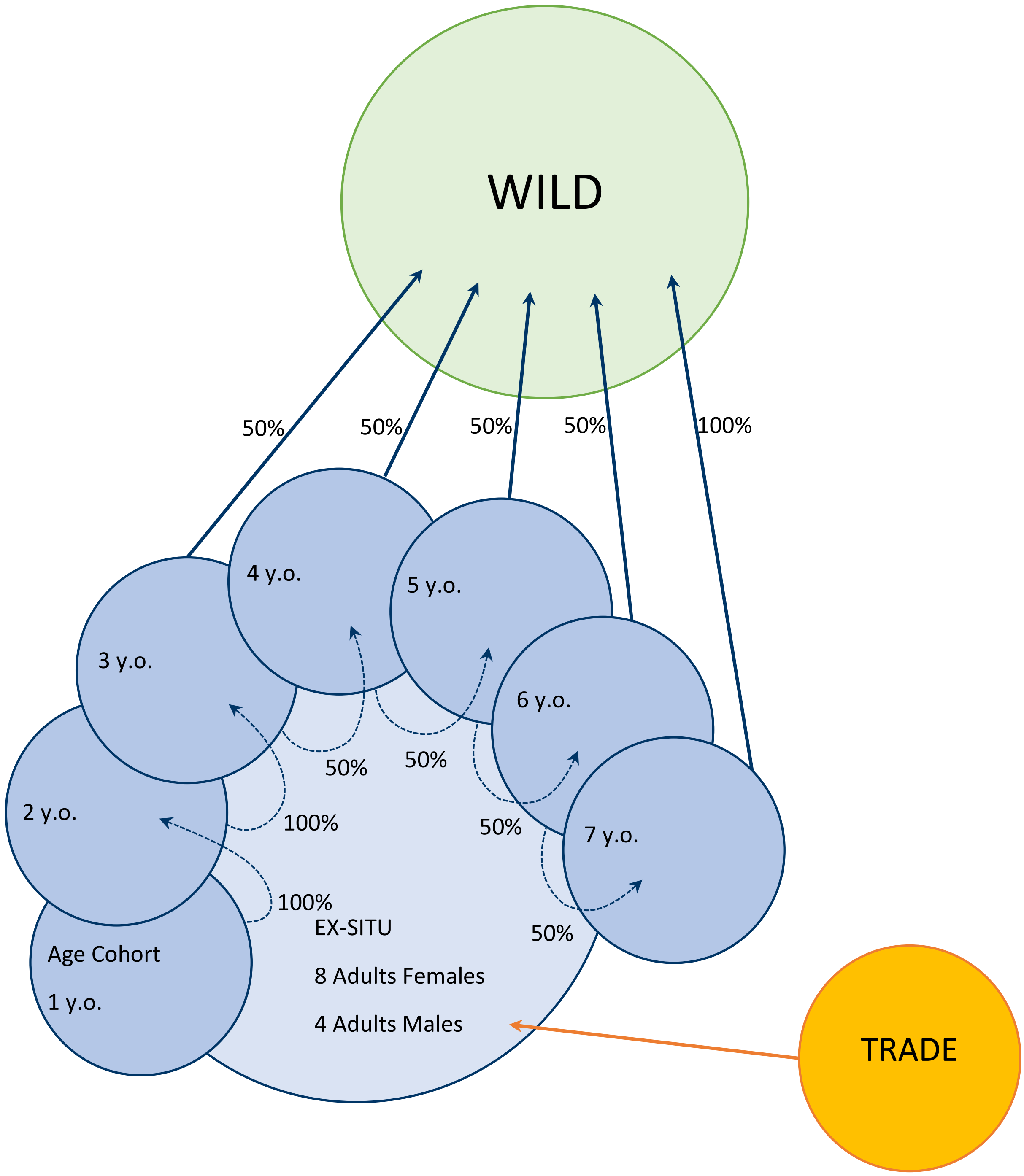
*The post-release mortality rate is a once-off rate for the 12 months following release; after that initial post-release year, the survivors should have the same annual mortality rate as the in-situ (wild-born) animals.

As illustrated in Table 48, stochastic projections show a wild population that is not growing. Annual growth rate is negative (-3.2%; λ =0.968) and generation time (for both sexes) is 24 years. This is the result of both the high age-specific mortality rates in the models and the additional catastrophes added to represent potential environmental events such as typhoons and disease outbreaks.

Table 48. Illustrates population performance indicators for captive and wild models, with catastrophes included (wild models only).

Stochastic rates	Ex Situ	In Situ	In Situ (soft)	In Situ (except. Y)
Instantaneous growth rate (r)	0.24 ± 0.07	-0.027 ± 0.27	0.12 ± 0.35	-0.01 ± 0.33
Gene Diversity (GD) at 50 yrs	0.94%	79%	27%	65%
Extinction Risk (P(Ex))	0%	81%	79%	0.95
N (Ext)	250.1 ± 7.1	34.6 ± 38.8	184.4 ± 88.1	102.9 ± 90.6
N (All)	250.1 ± 7.1	6.42 ± 21.2	134.3 ± 111.8	36.1 ± 72.6

Figure 29. Illustration of the model for Scenario 1. The core captive population (in blue) is composed of 12 adults (8 females and 4 males). Lost adults are replaced with unrelated adults from trade confiscations (orange). Juvenile turtles are grouped in annual cohorts (from age 1 to age 7) within the captive facility. Each age cohort has a different release rate: some individuals are held back in the captive facility (dashed blue arrows) while some are released to the wild (plain blue arrow). Note that different post-release survival rates are also implemented (see Table 47).



Scenario 1. Results

Figure 30 shows results for Scenario 1. As illustrated, regular releases from the captive population, at the rates specified, result in growth of the wild population to an average of more than 100 individuals over the 100-year period modelled (Mean N at 100 years = 108.1 ± 65.4). The captive population remains relatively stable throughout the period, as would be expected, given any adults are immediately replaced with confiscated specimens. Neither population goes extinct.

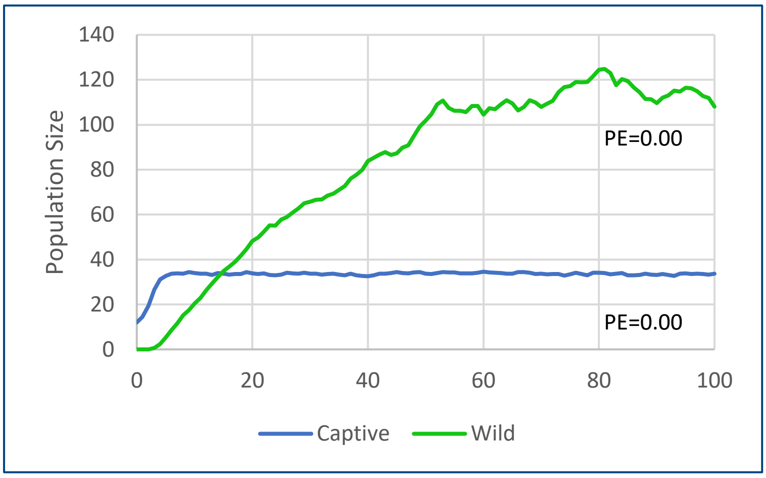


Figure 30. Scenario 1 results showing mean population size over time for: the captive population (blue); and the wild population (green).

Scenario 2. Supplementation stops after fifty years

In this scenario, after 50 years there are no further releases. All other parameters remain the same as in Scenario 1.

Results

Immediately after releases from the *ex-situ* facility cease, the wild population declines towards extinction. By 100 years, 44% of the populations simulated in VORTEX are extinct. The threats included in the wild model result in too many deaths to be compensated for by wild breeding rates and ongoing supplementation from captivity is required to sustain the population.

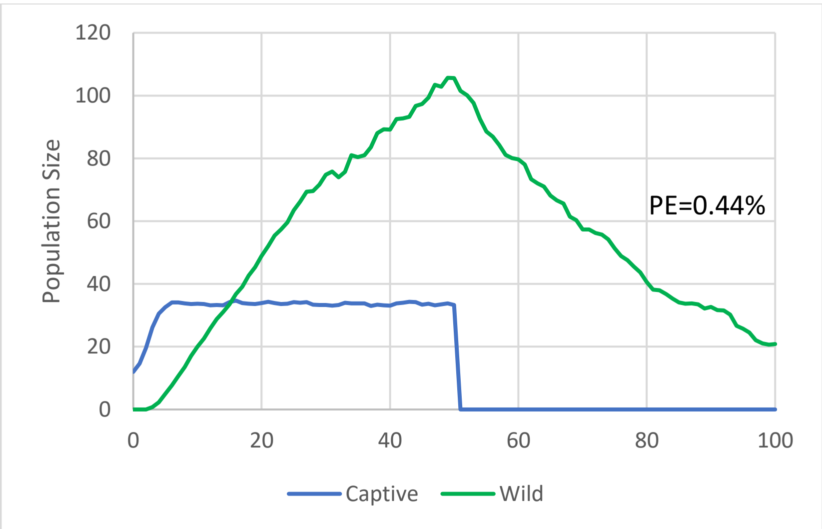


Figure 31. Scenario 2 results with releases stopped at year 50, showing mean population size over time for: the captive population (blue); and the wild population (green).

Scenario 3. Supplementation stops, mortality is reduced

All scenarios in this section are based on Scenario 2 (releases stop after 50 years) and are designed to explore the impact of lowering mortality rates in three different ways: a) by halving all mortality rates; b) by removing the effect of inbreeding on juvenile mortality; and c) by removing the effect of environmental threats (see Table 46).

Scenario 3a – halved mortality rates

In Scenario 3a, we halved the mortality rates of all age classes, in *ex-situ* and wild populations. We also halved the mortality associated with translocation. As a result, the decline of the wild population continues beyond year 50 but is more gradual. Extinction risk is still relatively high over the period (P(Ex)=19%) (see Figure 32).

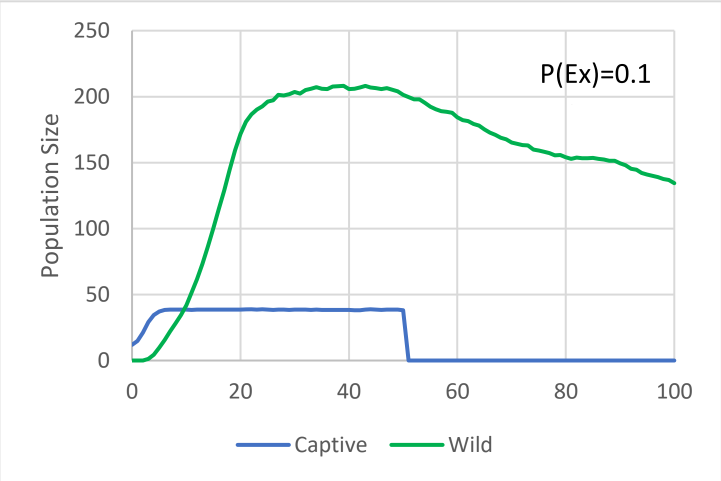


Figure 32. Scenario 3a. - releases stop at year 50 and mortality is halved. Graph shows mean population size over time for: the captive population (blue); and the wild population (green).

Scenario 3b – inbreeding turned off

In Scenario 3b. we supressed the impact of inbreeding in the population. In the model, as individuals become more inbred, their first-year survival rate is reduced, as measured in real populations. Though inbreeding can also have impacts beyond the first year this is not included in the models. As illustrated in Figure 33, the decline of the wild population beyond year 50 is again more gradual. Extinction probability is decreased by 2% (without inbreeding: 44%; with inbreeding: 46%).

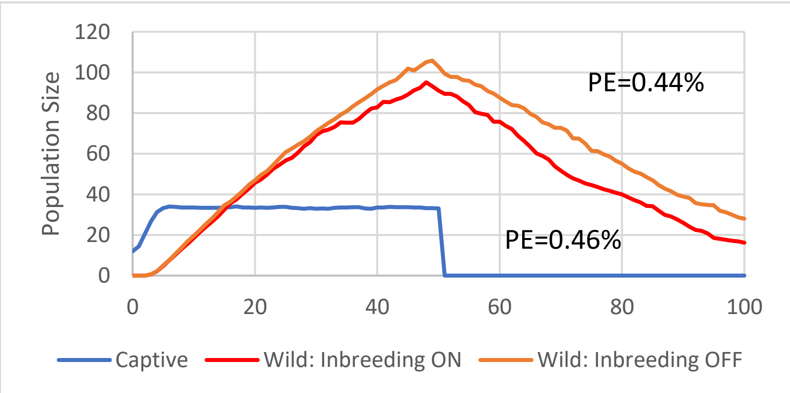


Figure 33. Scenario 3b results with releases stopped at year 50 and inbreeding depression switched off. Mean population size over time is shown for: the captive population (blue); and the wild population with (orange) or without (red) inbreeding depression.

Scenario 3c – environmental catastrophes suppressed

In Scenario 3c, we supressed the impact of the catastrophes threatening wild populations (Typhoon, Fires, Poaching, Disease). We removed threats one at a time to illustrate their individual impact (see Figure 34). In the absence of disease outbreaks the risk of extinction drops considerably (from 44% to 17% - see Table 50) and the removal of fires also has a large effect (reducing P(Ex) to 32%).

Modification	P(Ex)	N
All	44%	18.2 ± 32.9
No Typhoon	44%	23.8 ± 42.1
No Poaching	42%	25.7 ± 43.1
No Fire	32%	42.2 ± 54.3
No Disease	17%	32.9 ± 41.3

Table 50. Scenario 3c – suppression of environmental catastrophes. Extinction risk and population size after 100 years.

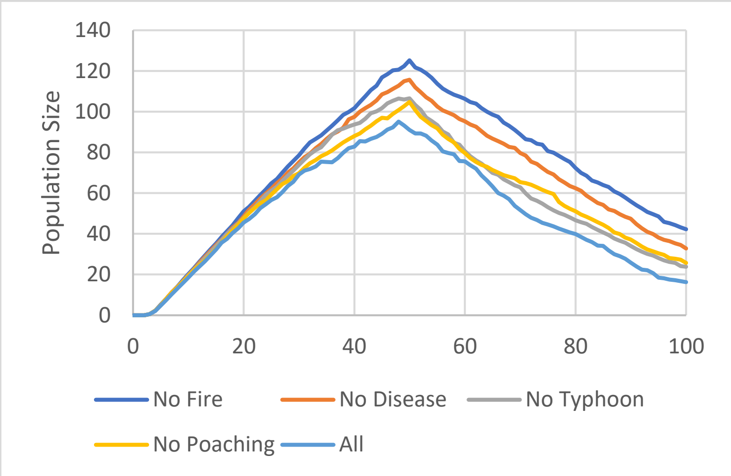


Figure 34. Scenario 3c results with releases stopped at year 50 and showing the impact of removing each individual catastrophes, leaving the others in place.

Finally, we cumulatively removed threats in order of impact (Disease > Fires > Poaching > Typhoon). Table 51 shows that the combination of Fire and Disease outbreak are the most lethal for the population. Without them the extinction probability drops to 1%. Note though that the population still declines due to other factors

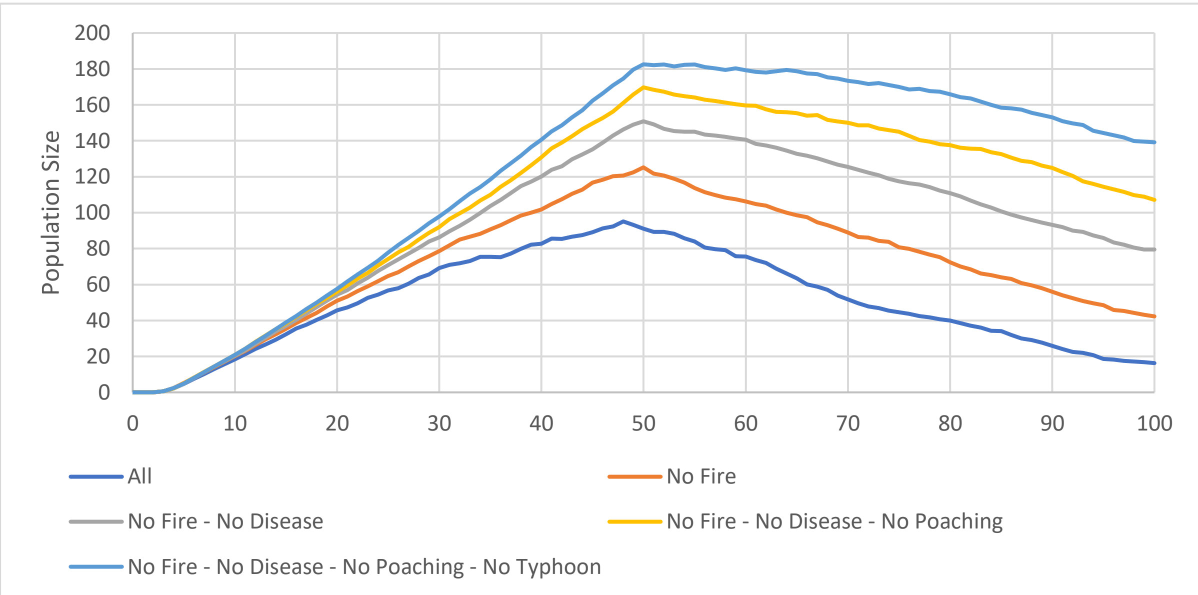


Figure 35. Scenario 3c results with releases stopped at year 50 and showing the impact of cumulatively removing threats in order of impact (Disease > Fires > Poaching > Typhoon).

Modification	P(Ex)	N
All	44%	18.15 ± 32.9
No Fire	32%	42.19 ± 54.34
No Fire - No Disease	1%	79.57 ± 61.08
No Fire - No Disease - No Poaching	1%	107.07 ± 61.33
No Fire - No Disease - No Poaching - No Typhoon	0%	139.25 ± 57.44

Table 50. Scenario 3c – cumulative suppression of environmental catastrophes. Extinction risk and population size after 100 years.

From the Scenario 3 models we can discern that no single factor can be adjusted (plausibly) to create growth in the wild models once supplementation stops. The removal of Disease and Fire can significantly reduce extinction risk but this would have to be coupled to additional measures (such as a considerable reduction in modelled mortality rates across the population) to reverse declines.

Scenario 4. Translocation rates increase

In this last section, the effects of increasing translocation rates from the *ex-situ* population are explored. Models are based on Scenario 1 and supplementation is stopped after 50 years. Two approaches are taken: a) the size of the captive breeding population is increased; and b) supplementation after year 50 occurs only when wild population numbers are dramatically low (e.g., after a catastrophic event). This is done for investigation only; stopping and starting the captive program in an ongoing way is not feasible.

Scenario 4a

The number of adults in the *ex-situ* population was increased incrementally from the baseline of 12, to 18, 24, 30 and 36, applying the same sex-ratio skew (33% males). Results are summarised in Figure 36 and Table 51. Although a larger number of breeders in the facility undoubtedly helps the wild population to grow larger more quickly, when supplementation ceases the population still declines.

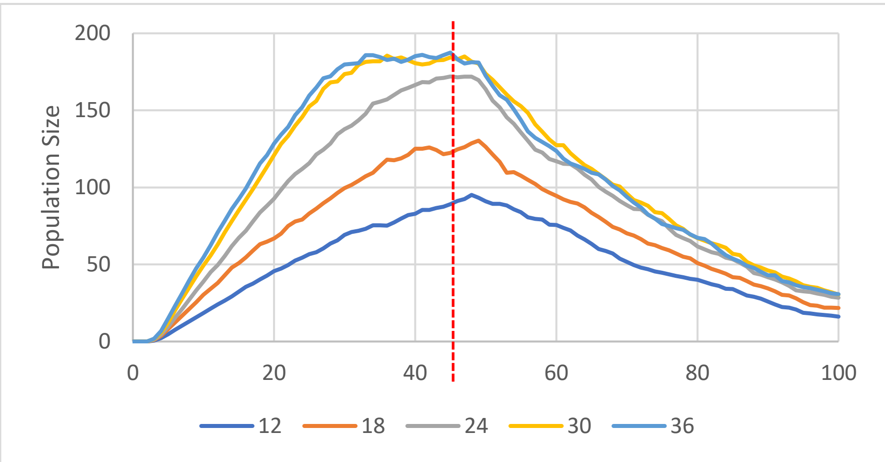


Figure 36. Scenario 4a. Population size of a wild population supported by *ex situ* facilities of 12 (Baseline), 18, 24, 30 and 36 individuals

Breeding Adults in *ex-situ* population	P(Ex)	N
12	44%	18.15 ± 32.9
18	49%	20.14 ± 36.5
24	41%	29.28 ± 46.9
30	38%	32.6 ± 48.8
36	40%	31.3 ± 49.3

Table 51. Scenario 4a population size and extinction risk after 100-year long simulation for a wild population supported by *ex situ* facilities of 12 (Baseline), 18, 24, 30 and 36 individuals.

Scenario 4b – beyond 50 years, occasional translocations are triggered by population crashes

In Scenario 4b, populations are rescued in situations where a threat drastically reduces the wild population. Specifically, 10 animals (5 males, 5 females) are added whenever population size in the wild dropped below N=20. As gathering 10 individuals to supplement might be difficult, supplementation events are only allowed to happen every 5 years. If the animal count drops to zero in between two supplementation events, the population is considered lost. Figure 37 illustrates the impact of this sporadic supplementation. Supplementation has a significant effect on extinction risk, which drops from 44% without supplementation to 12% with it. However, the average population size remains low (28.01 +/- 34.8), indicating that this occasional supplementation is enough to prevent extinction but not enough to drive growth.

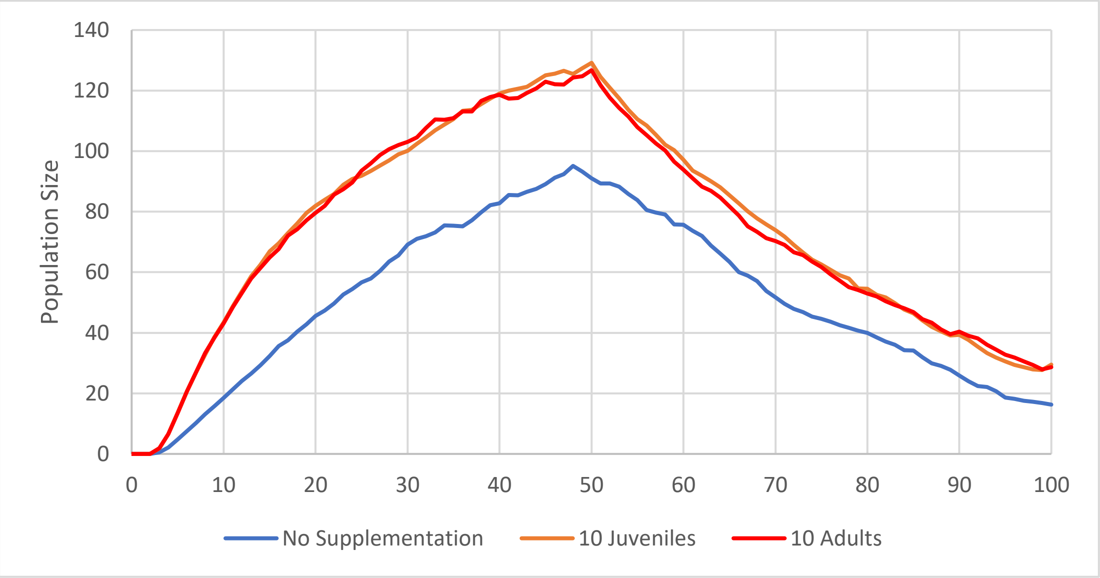


Figure 37. Scenario 4b. Population size of a wild population with occasional supplementation after 50 years with 10 turtles (5males, 5 females) only when the population drops to N=20.

Summary:

- Post-first-year mortality and number and size of clutches, are the parameters that modelled population growth rates are most sensitive to.
- Without the constant supplementation of individuals from the *ex-situ* population, wild populations as currently modelled decline to extinction in all scenarios due to a combination of high year-to-year, age-specific mortality, and periodic environmental catastrophes.
- Reducing threat impacts (and notably epidemic outbreak and wildfires) significantly improves the performance of wild populations but this is not enough to create growth.
- Without further modification to the wild and captive models we cannot create a plausible scenario in which a wild site is re-established from a captive population.
- Further work is needed to agree a plausible route through which captive releases can result in re-establishment of wild populations.

Results of preliminary models for other turtle species included in this Annamites project are included in the “Overview of Model Performance Section” and the parameters used to create them are provided in Appendix II below (these were provided by Peter Paul van Dijk).

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APPENDIX I: ADDITIONAL INFORMATION – VIETNAM PHEASANT

From Hubert Fryca

The following information from Hubert Fryca was submitted after the preliminary Vietnam Pheasant models had been completed and the analyses run. It would be useful to incorporate this information into future discussions and analyses. It is provided here to ensure that it travels with the rest of the information and assumptions.

Table 52. Additional information on hatching success for captive Vietnam Pheasants (*Lophura edwardsi* and *hatinhensis*)

Lophura edwardsi						
Female's identification	Age	Clutch size	Hatch	Survive 24hrs	Survive 30 days	Independent after
PL 10 16 D 151	3	3	3	3	3	3
	4	8	8	8	8	5
	5	5	5	5	5	3
	6	12	12	12	12	0
Lophura hatinhensis						
AV 12 D 33 169386	5	6	6	6	6	6
	6	9	9	9	9	7

- After several years of observation and treatment and comparisons, I come to the conclusion that Vietnam pheasant is sensitive to histomonas
- I noticed that young birds start to get sick within 3 months of life.
- Both chicks from the genus *Lophura* (other species such as: *jonesi* silver pheasants, lewis silver pheasant, *Lophura swinhoi*), *Polyplectron bicalcaratum bakerii*, *Gallus lafayetii*, tragopans did not have this problem, they will be in the same aviaries!
- I lost *Lophura edwardsi* only due to histomonas, *Lophura hatinhensis* had symptoms and the disease, but they were cured.
- I lost a *Lophura hatinhensis* by cannibalism by tragopans!

APPENDIX II. ADDITIONAL INFORMATION – TURTLES

Table A2.1. Estimated PVA Parameter Values for High Priority Annamites Turtles (showing values for: *Cuora bourreti, C. mouhotii, Sacalia quadriocellata,* and *Cyclemys pulchristriata*). All figures supplied by Pater Paul Van Dijk.

	Cuora bourreti		*Cuora mouhotii*		*Sacalia quadriocellata*		*Cyclemys pulchristriata*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild	Captive	Wild
Age at maturity (Females)								
Median	7	8	8	10	6	7	6	8
Min.	6	7	6	9	5	6	5	6
Max.	10	12	10	15	8	9	7	12
Annual reproductive output (eggs /female/year)								
Median	6	4	4	3	3	2	4	3
Min.	2	1	2	2	2	1	2	2
Max.	8	6	6	5	6	4	8	6
Time for newly-acquired breeding animals to adjust to captivity)(years)								
Median	2	-	2	-	2	-	1	-
Min.	1	-	1	-	1	-	1	-
Max.	4	-	3	-	3	-	2	-
Hatchling sex ratio (% males) (Captive ratios are actively manipulated)								
Median	33%	50%	33%	50%	33%	50%	33%	50%
Survival in year 1 (egg to 1 year after hatching)								
Median	75%	15%	75%	15%	75%	15%	75%	30%
Min.	25%	5%	25%	5%	25%	5%	50%	5%
Max.	90%	25%	90%	25%	90%	25%	95%	75%
Survival during year 1-2								
Median	90%	50%	90%	50%	90%	40%	85%	50%
Min.	50%	10%	50%	10%	75%	10%	75%	25%
Max.	100%	75%	98%	75%	95%	75%	95%	80%
Survival during years 3 to maturity age (average annual survival rate)								
Median	95%	90%	95%	90%	95%	75%	90%	80%
Min.	80%	75%	80%	75%	85%	50%	75%	50%
Max.	100%	95%	98%	95%	98%	90%	98%	95%
Survival during maturity (annual)								
Median	95%	98%	95%	98%	95%	98%	95%	98%
Min.	90%	95%	90%	95%	90%	95%	90%	95%

	Cuora bourreti		*Cuora mouhotii*		*Sacalia quadriocellata*		*Cyclemys pulchristriata*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild	Captive	Wild
Max.	98%	99%	98%	99%	98%	99%	98%	99%
Female longevity (hatching to death)(years)								
Median	50	50	50	50	30	42	50	50
Min.	10	20	10	20	20	40	30	30
Max.	75	75	75	75	50	45	75	75
Carrying capacity (ecological minimum)								
Adults per hectare	-	1	-	1	-	-	-	-
Juvs per hectare	-	2	-	2	-	-	-	-
Adults per 100 meters of stream	-	-	-	-	-	2	-	2
Juvs per 100 meters of stream	-	-	-	-	-	5	-	5
Release adjustment mortality								
% increased mortality in the first 12 months after release into the wild	-	30%	-	25%	-	25%	-	15%
Catastrophes								
Poaching (PA breakdown)								
Chance (%)	-	5%	-	5%	-	5%	-	5%
Impact: % adult population removed	-	50%	-	20%	-	10%	-	10%
Impact: % juve population removed	-	10%	-	5%	-	5%	-	10%
Theft (at breeding center)								
Chance (%)	5%	-	5%	-	5%	-	5%	-
Impact: % adult population removed	50%	-	40%	-	0	-	0	-
Impact: % juve population removed	50%	-	20%	-	10%	-	10%	-
Fire/wildfire								
Chance (%)	0%	2%	0%	2%	0%	2%	0%	2%
Impact: % adult population removed	-	50%	-	30%	-	5%	-	5%
Impact: % juv. population removed	-	80%	-	40%	-	5%	-	5%
Typhoon/flood								
Likelihood: (%)	5%	5%	5%	5%	5%	5%	5%	5%
Impact: % adult population removed	1%	5%	1%	5%	1%	5%	1%	1%
Impact: % juv. population removed	5%	10%	5%	10%	5%	10%	5%	5%

Table A2.2 Estimated PVA Parameter Values for High Priority Annamites Turtles (showing values for: *Platysternon megacephalum, Manouria impressa* and *Palea steindachneri*). All figures supplied by Pater Paul Van Dijk.

	Platysternon megacephalum		*Manouria impressa*		*Palea steindachneri*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Age at maturity (Females)						
Median	6	8	10	12	5	8
Min.	5	6	8	10	3	5
Max.	8	12	15	15	6	10
Annual reproductive output (eggs /female/year)						
Median	5	3.6	9	9	18	15
Min.	4	1	4	8	15	10
Max.	6	8	10	10	20	20
Time for newly-acquired breeding animals to adjust to captivity)(years)						
Median	2	-	3	-	1	-
Min.	1	-	2	-	1	-
Max.	4	-	5	-	3	-
Hatchling sex ratio (% males) (Captive ratios are actively manipulated)						
Median	33%	50%	33%	50%	50%	50%
Survival in year 1 (egg to 1 year after hatching)						
Median	60%	30%	25%	15%	80%	10%
Min.	25%	5%	5%	5%	50%	2%
Max.	74%	75%	50%	25%	90%	25%
Survival during year 1-2						
Median	75%	50%	50%	50%	95%	50%
Min.	40%	25%	25%	10%	90%	25%
Max.	90%	80%	80%	75%	98%	75%
Survival during years 3 to maturity age (average annual survival rate)						
Median	85%	80%	80%	90%	95%	75%
Min.	60%	50%	50%	75%	90%	50%
Max.	95%	95%	95%	95%	98%	90%
Survival during maturity (annual)						
Median	95%	98%	95%	98%	98%	97%
Min.	90%	95%	90%	95%	95%	90%
Max.	99%	99%	99%	99%	99%	99%
Female longevity (hatching to death)(years)						
Median	50	50	25	35	50	40
Min.	25	25	10	25	30	30
Max.	75	75	40	50	75	50

	Platysternon megacephalum		*Manouria impressa*		*Palea steindachneri*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Carrying capacity (ecological minimum)						
Adults per hectare	-	-	-	1	-	1
Juvs per hectare	-	-	-	2	-	3
Adults per 100 meters of stream	-	2	-	-	-	-
Juvs per 100 meters of stream	-	4	-	-	-	-
Release adjustment mortality						
(% increased mortality in the first 12 months after release into the wild)	-	25%	-	30%	-	10%
Catastrophes						
Poaching (PA breakdown)						
Chance (%)	-	5%	-	5%	-	5%
Impact: % adult population removed	-	50%	-	10%	-	5%
Impact: % juve population removed	-	50%	-	5%	-	0
Theft (at breeding center)						
Chance (%)	5%	-	5%	-	10%	-
Impact: % adult population removed	80%	-	80%	-	50%	-
Impact: % juve population removed	80%	-	80%	-	10%	-
Fire/wildfire						
Chance (%)	0%	2%	0%	2%	0%	2%
Impact: % adult population removed	-	2%	-	50%	-	0
Impact: % juv. population removed	-	5%	-	80%	-	0
Typhoon/flood						
Likelihood: (%)	5%	5%	5%	5%	5%	5%
Impact: % adult population removed	25%	1%	1%	1%	5%	1%
Impact: % juv. population removed	25%	5%	5%	2%	10%	1%

Table A2.3. Estimated PVA Parameter Values for Lower Priority Annamites Turtles (showing values for: *Cuora galbinifrons*, *C. picturata*, and *C. trifasciata/cyclornata*). All figures supplied by Pater Paul Van Dijk.

	Cuora galbinifrons		*Cuora picturata*		*Cuora trifasciata/cyclornata*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Age at maturity (Females)						
Median	7	8	6	7	6	10
Min.	6	7	5	6	4	8

	Cuora galbinifrons		*Cuora picturata*		*Cuora trifasciata/cyclornata*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Max.	10	12	8	10	10	15
Annual reproductive output (eggs /female/year)						
Median	6	4	6	4	6	5
Min.	2	3	2	3	2	2
Max.	8	8	8	8	13	8
Time for newly-acquired breeding animals to adjust to captivity)(years)						
Median	2	-	3	-	2	-
Min.	1	-	2	-	1	-
Max.	4	-	5	-	3	-
Hatchling sex ratio (% males) (Captive ratios are actively manipulated)						
Median	33%	50%	33%	50%	33%	50%
Survival in year 1 (egg to 1 year after hatching)						
Median	75%	15%	75%	15%	75%	15%
Min.	25%	5%	25%	5%	25%	5%
Max.	90%	25%	90%	25%	90%	25%
Survival during year 1-2						
Median	90%	50%	90%	50%	95%	50%
Min.	50%	10%	50%	10%	75%	10%
Max.	98%	75%	98%	75%	98%	75%
Survival during years 3 to maturity age (average annual survival rate)						
Median	95%	90%	95%	90%	95%	75%
Min.	80%	75%	80	75%	85%	50%
Max.	98%	95%	98%	95%	98%	90%
Survival during maturity (annual)						
Median	95%	98%	95%	98%	95%	98%
Min.	90%	95%	90%	95%	90%	95%
Max.	98%	99%	98%	99%	98%	99%
Female longevity (hatching to death)(years)						
Median	50	50	50	50	50	50
Min.	10	20	10	20	40	25
Max.	75	75	75	75	75	75
Carrying capacity (ecological minimum)						
Adults per hectare	-	1	-	1	-	-
Juvs per hectare	-	2	-	2	-	-
Adults per 100 meters of stream	-	-	-	-	-	5
Juvs per 100 meters of stream	-	-	-	-	-	10
Release adjustment mortality						
(% increased mortality in the first 12 months after release into the wild)	-	30%	-	30%	-	25%

	Cuora galbinifrons		*Cuora picturata*		*Cuora trifasciata/cyclornata*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Catastrophes						
Poaching (PA breakdown)						
Chance (%)	-	5%	-	5%	-	5%
Impact: % adult population removed	-	50%	-	50%	-	50%
Impact: % juve population removed	-	10%	-	10%	-	10%
Theft (at breeding center)						
Chance (%)	5%	-	5%	-	10%	-
Impact: % adult population removed	50%	-	50%	-	80%	-
Impact: % juve population removed	50%	-	50%	-	80%	-
Fire/wildfire						
Chance (%)	0%	2%	0%	2%	0%	2%
Impact: % adult population removed	-	50%	-	50%	-	5%
Impact: % juv. population removed	-	80%	-	80%	-	20%
Typhoon/flood						
Likelihood: (%)	5%	5%	5%	5%	5%	5%
Impact: % adult population removed	1%	5%	1%	5%	1%	5%
Impact: % juv. population removed	5%	10%	5%	10%	5%	10%

Table A2.4 Estimated PVA Parameter Values for Lower Priority Annamites Turtles (showing values for: *Mauremys annamensis*, *Rafetus swinhoei*, *Pelodiscus variegatus*). All figures supplied by Pater Paul Van Dijk.

	Mauremys annamensis		*Rafetus swinhoei*		*Pelodiscus variegatus*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Age at maturity (Females)						
Median	8	10	12	15	4	4
Min.	7	8	10	10	3	3
Max.	10	15	20	25	5	5
Annual reproductive output (eggs /female/year)						
Median	11	5	200	100	6	5
Min.	5	4	0	20	4	5
Max.	17	6	200	150	8	6
Time for newly-acquired breeding animals to adjust to captivity)(years)						
Median	1	-	2	-	1	-

	Mauremys annamensis		*Rafetus swinhoei*		*Pelodiscus variegatus*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Min.	1	-	1	-	1	-
Max.	2	-	5	-	2	-
Hatchling sex ratio (% males) (Captive ratios are actively manipulated)						
Median	33%	50%	50%	50%	50%	50%
Survival in year 1 (egg to 1 year after hatching)						
Median	80%	10%	75%	10%	80%	10%
Min.	50%	5%	25%	2%	50%	2%
Max.	95%	25%	90%	25%	95%	20%
Survival during year 1-2						
Median	90%	50%	95%	50%	95%	50%
Min.	70%	10%	90%	25%	90%	25%
Max.	98%	75%	98%	75%	98%	70%
Survival during years 3 to maturity age (average annual survival rate)						
Median	95%	75%	95%	75%	95%	75%
Min.	85%	50%	90%	50%	90%	50%
Max.	98%	90%	98%	95%	99%	90%
Survival during maturity (annual)						
Median	95%	98%	98%	99%	97%	96%
Min.	90%	95%	95%	95%	90%	90%
Max.	98%	99%	99%	99.50%	99%	99%
Female longevity (hatching to death)(years)						
Median	40	40	90	90	25	20
Min.	25	25	50	50	10	10
Max.	>46	50	150	150	35	30
Carrying capacity (ecological minimum)						
Adults per hectare	-	4	-	0.1	-	2
Juvs per hectare	-	10	-	1	-	5
Adults per 100 meters of stream	-	-	-	-	-	-
Juvs per 100 meters of stream	-	-	-	-	-	-
Release adjustment mortality						
(% increased mortality in the first 12 months after release into the wild)	-	10%	-	10%	-	15%
Catastrophes						
Poaching (PA breakdown)						
Chance (%)	-	5%	-	5%	-	5%
Impact: % adult population removed	-	25%	-	5%	-	5%
Impact: % juve population removed	-	25%	-	0	-	0
Theft (at breeding center)						

	Mauremys annamensis		*Rafetus swinhoei*		*Pelodiscus variegatus*	
Values in grey are literature-derived; other values are estimates.	Captive	Wild	Captive	Wild	Captive	Wild
Chance (%)	10%	-	5%	-	5%	-
Impact: % adult population removed	80%	-	10%	-	0	-
Impact: % juve population removed	80%	-	50%	-	10%	-
Fire/wildfire						
Chance (%)	0%	2%	0%	2%	0%	2%
Impact: % adult population removed	-	5%	-	0	-	0
Impact: % juv. population removed	-	5%	-	0	-	0
Typhoon/flood						
Likelihood: (%)	5%	5%	5%	5%	5%	5%
Impact: % adult population removed	1%	5%	5%	1%	5%	1%
Impact: % juv. population removed	5%	10%	10%	1%	10%	1%