Captive Sumatran Rhinoceros Population Modeling

Andrea Putnam, PhD
San Diego Zoo Global
April 9, 2013

Summary

- Given the reproductive problems seen in the current captive Sumatran rhinoceros population, there is an 85%-98% probability that the captive population will go extinct in 50 years if no additional wild-caught animals are brought into captivity. This is true regardless of whether the population is managed as 2 separate populations with occasional transfers or one globally managed population with no impediment to transfer.

- To reduce the captive population's extinction probability below 10%, approximately 16 adult wild-caught rhinoceros need to be transferred into captivity and either be managed globally, or as 2 populations with an interbirth interval of 3 years (i.e. no fertility problems). If significant fertility problems persist in the captive population >16 wild-caught rhinoceros are necessary to sustain 2 captive populations with occasional transfers.

- Reproductive problems are currently the most significant impediment to captive population growth. Ensuring females can conceive every ~3 years significantly improves the sustainability of captive populations, and reduces the need for wild-caught animals.

- Compared to populations with a high rate of female subfertility the use of artificial insemination (AI) can reduce the probability of extinction by 15% assuming 25% of females receive AI with a 20% success rate/year.

- In order to maintain a captive population that is able to regularly transfer rhinoceros back into the wild 15 years from now, 24 animals need to be brought into captivity within the next 10 years to grow the captive population to a sufficient size without risk of extinction.

Please see the accompanying report for modeling methods and results.

Introduction

A Population Viability Analysis (PVA) was performed to analyze the sustainability of the global captive population of Sumatran rhinos using the software package VORTEX (v9.99; Lacey 1993). **Twenty management scenarios were modeled and demonstrated that the global population of captive Sumatran rhinos has a high risk of extinction over the long-term, but that extinction risk declines significantly through the addition of wild-caught animals and the improvement of reproductive success.**

A PVA is a computer-modeling tool that can be used to assess the current and future risk of population decline and extinction. The two factors that are often of the most interest for PVAs in captive populations are stochasticity in the lives of individuals and genetic changes in the population. Exploring the impact of these factors on a population though PVA modeling can help us understand and predict the probability of population extinction. Please see the Appendix for PVA methods and the parameters used for each scenario that was modeled. The specific management scenarios shown here were chosen because they were of interest to the captive management working group at the Sumatran Rhino Crisis Summit.

Scenarios Modeled

There are currently only 8 captive Sumatran rhinos considered to be reproductive without the use of reproductive techniques such as AI (Suci, Harapan, Tam, Andalas, Rosa, Ratu Andatu, Putung), and three of these rhinos have a low likelihood of unassisted reproductive success (Puntung, Rosa and Tam).

The captive population was divided into 2 regional breeding populations, the Sumatran Rhino Sanctuary (SRS) and the US. The potentially reproductive animals at SRS include Andalas, Rosa, Ratu, and Andatu. The potentially reproductive animals that would make up the US population are Suci, Tam, Puntung, and Harapan. Putung and Tam are currently housed in Sabah, thus, this scenario assumes their transfer to the US. **It is important to note that the specific animals within each population have little effect on the modeling results; what is important is that each population begins with 2 males and 2 females.**

These individuals form the basis of the global captive population used for modeling 20 scenarios that fall into 6 groups:

1. *Global management of all captive rhinos*. A global population assumes that all captive rhinos are managed as a single population. Two regional populations can approximate a global population if semen from all males is available across populations for AI. Scenarios were modeled with and without female subfertility (5 year versus 3 year interbirth interval).

2. *Two captive populations* (i.e. SRS and US). Scenarios are modeled with and without the addition of wild-caught rhinos. The occasional transfer of animals among populations is included in these scenarios, as scenarios with and without female subfertility.

3. *Captive breeding to supplement the wild population*. Wild-caught rhinos were added to both captive populations in the early years of the simulations. At year 15, 2 rhinos were transferred back to the wild from each population every 4 years thereafter.

4. *Best-case scenario*. These scenarios model a 2 year interbirth interval. This requires intensive breeding where a dam and calf are temporarily separated during mating of the dam and then re-joined until the calf is ready to be weaned. These scenarios were modeled with and without the addition of wild-caught animals.

5. *Natural breeding and AI*. Artificial insemination has not yet proven successful in Sumatran rhinos, but may prove feasible in the near future. Both conservative and realistic scenarios were modeled so that the number of females receiving AI and the probability of success varied.

6. *Parameters based on studbook data*. During the Summit, some working group members were interested in models that utilized the data from the 4 captive born individuals instead of relying on estimate of first-year mortality and age of first reproduction from African/Indian rhino data and hormonal data, respectively. However, because of the small sample size of the captive-born Sumatran rhinos these parameters may not represent the biology of the species.

Results

Please see Table 1 and Figures 1 and 2 for summaries of the models on the following pages. The Appendix contains tables with all results.

Table 1: The average probability of extinction (P(E)) and genetic diversity (GD) retained after 50 years.

Management Scenario	Realistic: 40% of females are subfertile	Best case: No subfertile females
2 Populations: No wild-caught rhinos added	P(E) = 98% GD = 59%	P(E) = 86% GD = 65%
2 Populations: 4 wild-caught rhinos added to each population over 3 years (8 total)	P(E) = 67% GD = 72%	P(E) = 12% GD = 82%
2 Populations: 8 wild-caught rhinos added to each population over 3 years (16 total)	P(E) = 36% GD = 78%	P(E) = 1% GD = 88%
Globally managed population: No wild-caught rhinos added	P(E) = 85% GD = 63%	P(E) = 45% GD = 71%
Globally managed population: 8 wild-caught rhinos added over the next 3 years	P(E) = 29% GD = 78%	P(E) = 1% GD = 87%
Globally managed population: 16 wild-caught rhinos added over the next 3 years	P(E) = 9% GD = 84%	P(E) = 0% GD = 92%
Captive populations supplement wild population: 18 rhinos added to captivity in first 10 years, then 2 removed from each subpopulation every 4 years beginning at year 15		P(E) = 64% GD = 80%
Captive populations supplement wild population: 24 rhinos added to captivity in first 10 years, then 2 removed from each subpopulation every 4 years beginning at year 15		P(E) = 14% GD = 88%
2 Year breeding interval: Intensive breeding in 2 populations with no wild-caught rhinos added		P(E) = 56% GD = 70%
2 Year breeding interval: Intensive breeding in 2 populations with 8 wild-caught added to each population		P(E) = 0% GD = 93%
Natural breeding and AI: Conservative - 40% of females receive AI with 15% probability of success/year, 8 wild-caught added to each population	P(E) = 21% GD = 81%	
Natural breeding and AI: Realistic - 25% of females receive AI with 20% probability of success/year, 8 wild-caught added to each population	P(E) = 5% GD = 86%	
Observed parameters with no wild-caught rhinos added: Mortality rates and reproductive ages based on 4 captive births		P(E) = 84% GD = 66%
Observed parameters with 16 rhinos added: Mortality rates and reproductive ages based on 4 captive births		P(E) = 1% GD = 88%

Figure 1: Average probability of extinction over 50 years in captive globally managed and 2-population scenarios. For 2-population scenarios, the average probability that one of the two populations goes extinct is shown.

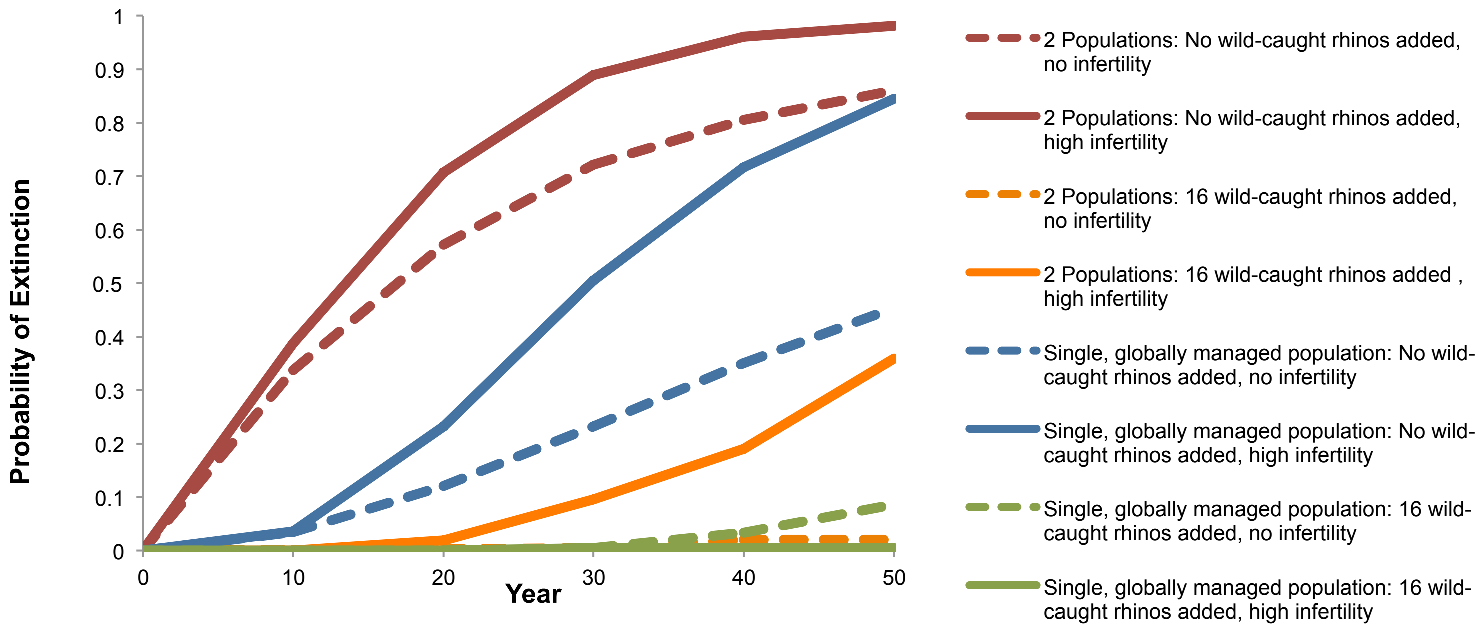
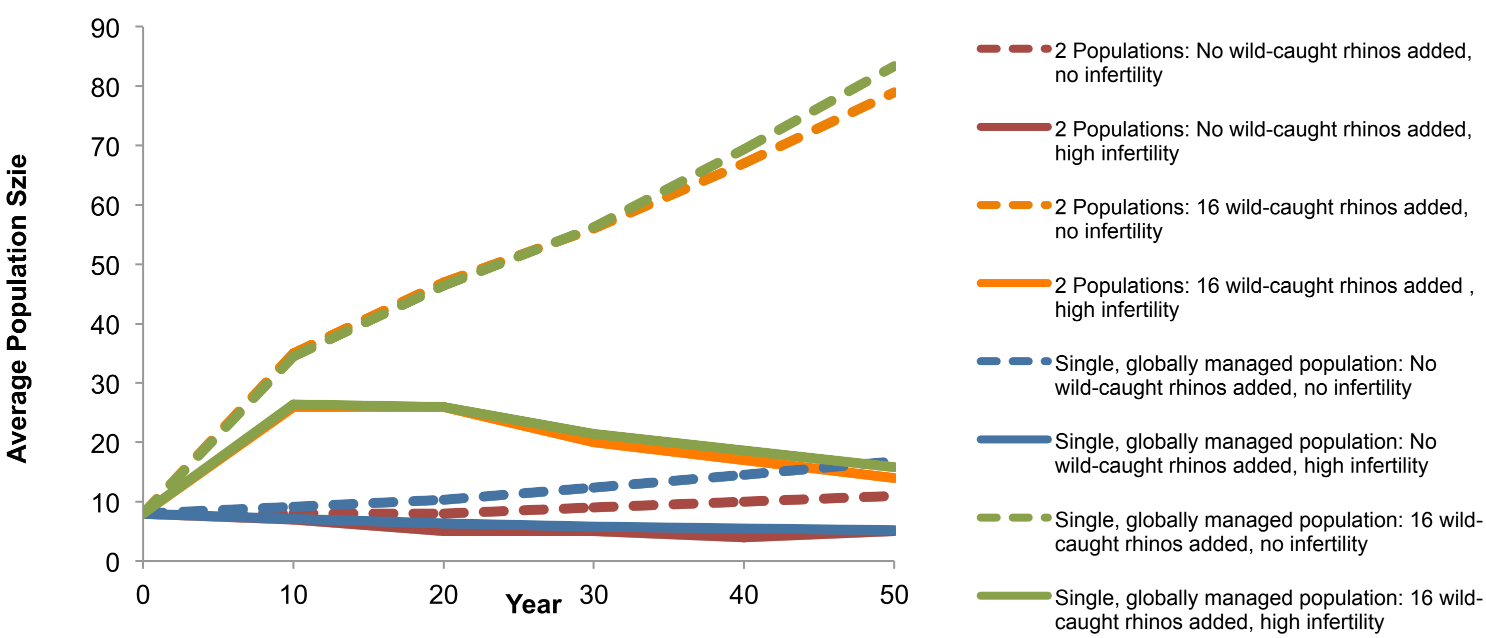


Figure 2: Average population size (of extant populations) over 50 years in captive globally managed and 2 population scenarios. For 2 population scenarios, the combined population size is shown.



Conclusion

Although care was taken to incorporate information that is available on Sumatran rhino biology, as well as previous PHVA work on wild Sumatran rhinos (Soemarna *et al*. 1994; Ellis *et al*. 2011) and information gleaned from other rhino species, projections should be considered to be *approximate guidelines* of future population persistence.

Effects of Management Decisions
Variation in extinction risk within captive populations is primarily determined by the number of wild-caught rhinos able to be transferred into captive management. Adding 8 adult wild-caught individuals to both captive populations over the next few years is predicted to reduce the current risk of combined captive population extinction by 62% - 85% depending on the proportion of females breeding each year.

Managing captive Sumatran rhinos as a single population greatly increased the probability of population persistence, when compared to scenarios for which captive animals were managed on a regional scale with reduced transfers among regional populations (Table 1). These results are consistent with the expectation that small fragmented populations have an increased risk of demographic instability and the effects of inbreeding on reproduction and survival (Gilpin and Soule 1986; Crnokrak 1999). Thus, while managing 2 captive populations is preferable as insurance against catastrophe in one population, frequent transfer of animals and/or semen for AI will improve the sustainability of the populations.

A primary goal of the captive population is to eventually maintain a sustainable population size that can be used to supplement the wild population. In order to grow the captive population to a size where rhinos can be removed from captivity and transferred to the wild, at least 12 wild-caught rhinos need to be added to each captive population within the first 10 years of the model. Beginning at year 15, 2 rhinos can be removed from each subpopulation every 4 years resulting in an extinction risk of 14% across the 2 populations.

Effects of Biological Parameters
The scenarios modeled here are extremely sensitive to the percentage of females able to breed each year, also known as the interbirth interval. Modeling increased mortality and even increasing the age of first reproduction had much less of an impact on population extinction risk than interbirth interval. Three out of the 4 Sumatran rhino births in captivity were born to Emi (SB# 29) who had an interbirth interval of ~ 3 years. Thus, an average interbirth interval of 3 years is used as a best-case management scenario. However, as almost half of the wild-caught captive Sumatran rhinos have compromised fertility, a greater interbirth interval was also modeled. An interbirth interval of 5 years is equivalent to 40% of females being subfertile while 60% have a 3 year interbirth interval, a realistic assumption given the reproductive problems in seen in the current captive population. The significant difference in extinction risk depending on if the interbirth interval is 3 years or every 5 is shown in Table 1.

Using AI in combination with natural breeding may decrease the probability of extinction across 2 populations by ~15% assuming 25% of females receive AI with a 20% success rate/year. This scenario assumes the remaining females have normal reproduction (an interbirth interval of 3 years). As AI has not yet proven successful in Sumatran rhinos, estimates of success rates are very tentative. If the success rate of AI is less than 20% or if a larger percentage of females require AI, the reduction in extinction risk becomes much less significant (see the Conservative AI model in Table 1).

In summary, results suggest that adding at least 16 wild-caught rhinos into the captive Sumatran subpopulation would have a significant impact on extinction risk. The current size of both the entire captive population is so small, adding only a few additional individuals notably impacts the degree to which chance events affect population demography and extinction risk. Although the effect was not as great, adding wild-caught rhinos did also improve both gene diversity retention. **Thus, preventing captive population extinction requires adding reproductive wild-caught rhinos to the current captive population in the short-term with the eventual goal to globally manage the population sustainably for the long-term**.

Citations

Crnokrak P, Roff DA. (1999) Inbreeding depression in the wild. Heredity. 83:260–270.

Ellis S, Ivy J, Ramono WS (2011) Future directions towards the persistence of the captive Sumatran rhino population. White Paper, 24 Jan 2011.

Gilpin ME, Soulé ME (1986) Minimum viable populations: The processes of species extinctions. In: *Conservation Biology: The Science of Scarcity and Diversity* (ed. Soulé M), Sunderland Mass: Sinauer Associates.

Lacy RC (1993) VORTEX: A computer simulation model for population viability analysis. Wildlife Research, 20, 45-65.

Lacy RC (2000) Structure of the VORTEX simulation model for population viability analysis. *Ecological Bulletins*, 48, 191-203.

Miller PS, Lacy RC (2003) *VORTEX: A Stochastic Simulation of the Extinction Process. Version 9 User's Manual*. Apple Valley, MN: Conservation Breeding Specialist Group (SSC/IUCN).

Ralls K, Ballou JD, Templeton A (1988) Estimates of lethal equivalents and the cost of inbreeding in mammals. *Conservation Biology*, 2, 185-193.

Soemarna K, Tilson R, Ramono W, Sinaga DW, Sukumar R, Foose TJ, Traylor-Holzer K, Seal U (1994) Sumatran rhino in Indonesia Population and Habitat Viability Analyiss Report. IUCN/SSP Captive Breeding Specialist Group.

Appendix

PVA Overview

Many factors and processes affect population persistence in captive populations including genetic changes in the population (such as genetic drift, inbreeding, and response to natural selection) and the chance results of the probabilistic events in the lives of individuals (such as breeding success and survival), and the interactions among these factors. This stochasticity in the lives of individuals and the potential genetic changes in the population are explored on the captive Sumatran rhino population though PVA modeling using the software VORTEX. These models can help us understand and predict the probability of population persistence. For a more detailed explanation of VORTEX and its use in PVAs, see Lacy (1993, 2000) and Miller and Lacy (2003).

Model Input Parameters

The International Sumatran Rhinoceros Studbook provides little data to inform model parameters because only a small number of Sumatran rhinos have been held in captivity (n = 49). Thus, parameters have been based on Sumatran rhino information provided by the IRF, previous PVA work on wild Sumatran rhinos, and analyses of other rhino studbooks (Appendix Table 1).

Number of Populations
The population was divided into 2 regional breeding groups, the SRS and the US. The potentially reproductive animals at the SRS include Andalas, Rosa, Ratu, and Andatu. The potentially reproductive animals that would make up the US population are Suci, Tam, Puntung, and Harapan. Tam and Puntung are currently housed in Sabah, thus, this scenario requires his transfer to the US.

Number of Years and Iterations
All scenarios were simulated 1000 times. The reported results were averaged across all iterations. Each model projection extended to 100 years to capture extinction risk across multiple generations, with demographic and genetic summarized at each year. Because current conservation management is concerned with shorter time frames, the results after 50 years are reported here.

Inbreeding depression
VORTEX allows the detrimental effects of inbreeding to be modeled by reducing the survival of offspring through their first year. Although no inbreeding depression studies have been conducted on rhinos, a survey of 40 other mammal taxa in captivity found that inbreeding depressed juvenile survival by a median effect of 3.14 “lethal equivalents” (Ralls et al. 1988). Until recently, Sumatran rhinos lived in large continuous tracts of forest. Given the species’ historic population size and range, there is no reason to suspect that
Sumatran rhinos have evolved an unusual tolerance of inbreeding. Thus, inbreeding depression was incorporated into the model and the effect on infant survival was assumed to be equivalent to that observed in other captive mammal populations; 3.14

lethal equivalents per individual, with 50% of the total genetic load derived from lethal alleles (the default values provided by VORTEX).

Breeding System
The breeding system was specified as polygamous, with each male being able to breed multiple females within a single year.

Age of first reproduction
VORTEX precisely defines reproduction as the time at which offspring are born, not simply the age of sexual maturity. Female Sumatran rhinos are thought to sexually mature between 6 years of age and males are thought to sexually mature at ~8 years of age. Although Sumatran rhinos have been recorded to breed at these ages, average age of reproduction may be older and will be modeled in the full report.

Maximum age of reproduction
VORTEX assumes that animals can reproduce throughout their entire adult lives and does not model reproductive senescence. Individuals are culled from the model once they surpass the specified maximum age. The maximum age of reproduction for both sexes was set at 25 years.

Offspring production
Females produce only one calf per parturition, with a birth sex ratio of 50% each sex.

Percent females breeding
The shortest inter-birth interval for a female Sumatran rhino that produces surviving offspring is approximately 3 years. Thus, under an optimistic model, ~33% of adult females can breed each year. This proportion of breeding females is likely to be unrealistically high for the global population of captive Sumatran rhinos, many of which have reduced fertility, so 20% of adult females breeding each year was also modeled.

Percent males in breeding pool
All adult males were available for breeding each year. In other words, it was assumed that there were no social or behavioral constraints that would restrict a male from breeding when he was physiologically capable.

Mortality rates
There are few data on the mortality rates observed in captive Sumatran rhinos. Based on average first-year and adult mortality rates for other captive rhino species, 15% and 5%, respectively, were used. These estimates will be discussed in greater detail in the full report.

Carrying capacity
A carrying capacity of 200 animals for each population was imposed on the model. Future carrying capacities for the captive population are currently unclear, but given current population parameters a capacity of 200 animals was unlikely to significantly impact general projection results.

Genetic management and breeding pair selection

Genetic management is often relaxed at the onset of captive breeding programs, while the population is still growing and demographically unstable due to small population size. Thus, given the current status of the global population of captive Sumatran rhinos, breeding pairs were selected at random for the purposes of these analyses. Although breeding was at random, close inbreeding was avoided by disallowing breeding between first-order relatives; breeding between individuals with a kinship coefficient of 0.25 or higher was rejected.

Transfer rates
Transfer rates were specified for scenarios that modeled 2 populations of captive Sumatran rhinos. Although VORTEX models transfers (dispersals, migrations, etc.) on a yearly basis, it is unlikely that regional subpopulations would exchange animals annually. Still, to model low levels of exchange between subpopulations, a 2% yearly transfer rates between the two populations was modeled. The model restricted transfers to younger, reproductive animals 10-20 years of age, and assumed that no animals suffered mortality during transfer.

Summary of Scenario Parameters

Parameters	Baseline	2 Year Interbirth	Use of AI	Surplus	Studbook Parameters
# of populations	2	2	2	2	2
inbreeding depression included?	yes	yes	yes	yes	yes
environmental variation included?	no	no	no	no	no
breeding system	polygamous	polygamous	polygamous	polygamous	polygamous
age of first reproduction (♂ / ♀)	8/6	8/6	8/6	8/6	10/7
maximum age of reproduction	25	25	25	25	25
annual % adult females breeding	20, 33	50	23, 29	33	33
% males in breeding pool	100	100	100	100	100
litter size	1	1	1	1	1
offspring sex ratio	0.5	0.5	0.5	0.5	0.5
% annual mortality					
0-1 years	15	15	15	15	5
1-40 years	5	5	5	5	5
initial population size	8 breeding animals	8 breeding animals	8 breeding animals	8 breeding animals	8 breeding animals
carrying capacity	200 total (100 per subpopulation)	200 total (100 per subpopulation)	200 total (100 per subpopulation)	200 total (100 per subpopulation)	200 total (100 per subpopulation)
% transfer rates	2	2	2	2	2
breeding pair selection	random	random	random	random	random
genetic management	avoid close inbreeding (0.25)	no / avoid close inbreeding (0.25)	avoid close inbreeding (0.25)	no / avoid close inbreeding (0.25)	avoid close inbreeding (0.25)
years to simulate	50, 100	50, 100	50, 100	50, 100	50, 100
supplementation	0, 4.4 (1.1 at year 1 and year 3, for each pop =8 total), 8.8 (2.2 at year 1 and year 3, for each pop =16 total)	0, 8.8(2.2 at year 1 and year 3, for each pop =16 total)	0, 8.8(2.2 at year 1 and year 3, for each pop =16 total)	3.3 and 6.6 (added Years 1,3,6 to each pop)	0, 2.2
surplus (for supplementation in the wild)	no	no	no	Remove 1.1 every 4 years from each pop, beginning at year 15	no

Appendix Table Legend: For all scenarios except the global population, 2 populations (each starting with 4 individuals) were modeled with 2% of animals transferred between populations each year. The values reported in the table are the unweighted averages across populations as there was little difference in the population outcomes within each scenario.

PE: Probability of extinction, assessed as the percent of simulated populations to go extinct by a given year.

N ± SD: Mean size of the simulated populations still extant at a given year, ± standard deviation.

GD ± SD: Gene diversity (expected heterozygosity) of extant populations at a given year calculated as a percent of the initial gene diversity, ± standard deviation.

Appendix Table 1

		50 Years		
Scenario	**Interbirth Interval**	**PE (%)**	**N ± SD**	**GD (%) ± SD**
2 Populations: No wild-caught rhinos added	5	98	4 ± 2	59 ± 13
2 Populations: No wild-caught rhinos added	3	86	8 ± 7	65 ± 11
2 Populations: 4 wild-caught rhinos added to each population over the next 3 years (8 total)	5	67	7 ± 4	72 ± 10
2 Populations: 4 wild-caught rhinos added to each population over the next 3 years (8 total)	3	12	24 ± 16	82 ± 8
2 Populations: 8 wild-caught rhinos added to each population over the next 3 years (16 total)	5	36	9 ± 5	78 ± 9
2 Populations: 8 wild-caught rhinos added to each population over the next 3 years (16 total)	3	1	40 ± 21	88 ± 5
Single, globally managed population: No wild-caught rhinos added	5	85	5 ± 3	63 ± 14
Single, globally managed population: No wild-caught rhinos added	3	45	17 ± 13	71 ± 11

Scenario	Interbirth Interval	PE (%)	N ± SD	GD (%) ± SD
Single, globally managed population: 8 wild-caught rhinos added over the next 3 years	5	29	12 ± 7	78 ± 10
Single, globally managed population: 8 wild-caught rhinos added over the next 3 years	3	1	51 ± 27	87 ± 5
Single, globally managed population: 16 wild-caught rhinos added over the next 3 years	5	9	16 ± 10	84 ± 7
Single, globally managed population: 16 wild-caught rhinos added over the next 3 years	3	0	83 ± 37	92 ± 3
*Captive populations supplement wild populatio*n: 18 rhinos added to captivity in first 10 years, then 2 removed from each subpopulation every 4 years beginning at year 15	3	64	17 ± 13	80 ± 9
Captive populations supplement wild population: 24 rhinos added to captivity in first 10 years, then 2 removed from each subpopulation every 4 years beginning at year 15	3	14	31 ± 21	88 ± 6
*2 Year breeding interva*l: Intensive breeding with no wild-caught rhinos added	2	56	22 ± 20	70 ± 11
2 Year breeding interval: Intensive breeding with 16 wild-caught rhinos added over 3 years	2	0	164 ± 42	93 ± 2
Natural breeding and AI: Conservative - 40% of females receive AI with 15% probability of success/year, 8 wild-caught added to each population	4.3	21	12 ± 8	81 ± 8
Natural breeding and AI: Realistic - 25% of females receive AI with 20% probability of success/year, 8 wild-caught added to each population	3.6	5	25 ± 15	86 ± 6
Observed parameters with no wild-caught rhinos added: Mortality rates and reproductive ages based on 4 captive births	3	84	8 ± 7	66 ± 14
Observed parameters with 16 rhinos added: Mortality rates and reproductive ages based on 4 captive births	3	1	40 ± 22	88 ± 5