Future Directions Towards the Persistence of the Captive Sumatran Rhino Population

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EXECUTIVE SUMMARY

No more than 200 Sumatran rhinos are thought to remain in fragmented populations on Sumatra and Borneo. In addition to the wild population, there are 10 Sumatran rhinos in captivity (five in Indonesia, two in Sabah, Malaysia, and three in the United States) for purposes of breeding, research and education. The captive Sumatran rhino population is overseen by the Sumatran Rhino Global Propagation and Management Board (GMPB), which was established in 2005. The GMPB is comprised of NGOs, governments, private donors, zoos and other international rhino conservation organizations. In February 2010 the GMPB met in Bogor, Indonesia to develop a proactive strategy to address the loss of the only breeding female and to move the captive population towards optimally supporting the wild population. Two main recommendations emerged from the meeting: (1) that the population needs to be managed under a truly global management system and (2) that new genetic material is needed to decrease its risk of extinction and enhance its viability.

As part of the research to substantiate these recommendations, a Population Viability Analysis (PVA) was carried out to analyze the potential persistence of the captive population of Sumatran rhinos. The software package VORTEX (v9.98; Lacy 1993) was used to develop a PVA for the global population of captive Sumatran rhinos. All modeled scenarios demonstrated that the global population of captive Sumatran rhinos has a moderate to high risk of extinction over the long-term, but that extinction risk declined if all captive animals could be managed as a single population rather than managed as regional subpopulations with limited transfers between geographic areas.

The present analyses suggest that the two most important management actions are (1) managing the captive Sumatran rhino population on a global basis and (2) adding animals to the global population to contribute to its long term persistence. The modeled scenario had the biggest positive impacts on the viability of the global population of captive Sumatran rhinos combined importing a pair of wild-caught rhinos into the Sumatran subpopulation, importing a wild-caught male into the US subpopulation, and transferring female #45 to the US. If all captive animals were managed as a single population (assuming 33% of females breeding; 15% first-year mortality), this combination of scenarios eliminated the risk of population extinction over the next 25 years and decreased

extinction risk by 20% over the next 100 years. There is an urgent need for decisive management action for the captive population of Sumatran rhinos. The authors urge the GMPB members, particularly the governments of Indonesia and Malaysia, to seriously consider these recommendations, and to act on them as soon as possible to strengthen the global captive Sumatran rhino population.

BACKGROUND

Sumatran Rhinos in Nature

No more than 200 Sumatran rhinos *(Dicerorhinos sumatrensis sumatrensis)* survive in fragmented populations on the islands of Sumatra and Borneo. Sumatran rhinos may well be the most endangered of all rhino species, due to their rapid rate of decline – more than 50% over the last decade. The species is listed as Critically Endangered on the IUCN Red List of Threatened Species (van Strien *et al*. 2008).

Indonesia. The Sumatran rhino population in Indonesia is spread across three major parks containing some of the most critical remaining tropical forest habitats in Indonesia. These parks are each home to numerous threatened species and provide critical ecosystem services for local human populations. There are between 50 and 70 animals in Sumatra's Bukit Barisan Selatan National Park and an estimated 27-35 rhinos in Way Kambas National Park (Yayasan Badak Indonesia, unpublished data). Surveys are planned in northern Sumatra's Gunung Leuser National Park – the other major Sumatran rhino site in Indonesia – in 2011. Previous estimates were that Gunung Leuser held between 60 and 80 individuals (Indonesia Ministry of Forestry 2007), but this has not been confirmed.

Malaysia. Sabah, Malaysia is believed to hold approximately 20-30 rhinos in fragmented populations of questionable viability. Rhino numbers and signs of breeding at Tabin Wildlife Reserve and Danum Valley Conservation Area (the sites which probably represent the last hopes for saving this rhino), seem not to have changed dramatically for the past 30 years (J. Payne *in litt*.). Peninsular Malaysia's rhino populations have experienced severe losses over the past few years; most Asian rhino experts concur that their continued existence is improbable.

Sumatran Rhinos in Managed Breeding Centers and Programs

Because of the challenges and uncertainties of conserving the Sumatran rhino in the wild, in 1984 the IUCN/SSC Asian Rhino Specialist Group recommended and facilitated the development of a captive propagation program. This program was developed using rhinos living in extremely fragmented habitats and/or in isolated situations with no opportunity to breed. In the early 1990s, managed propagation centers known as "sanctuaries" were established in range states and some captive rhinos were repatriated to these locations.

Today, there are a total of 10 Sumatran rhinos in captivity (five in Indonesia, two in Sabah, Malaysia, and three in the United States) for purposes of breeding, research and education. These animals are tracked in the International Sumatran Rhinoceros Studbook. A number of NGOs, most notably the International Rhino Foundation and the Borneo Rhino Alliance (formerly SOS Rhino) have invested millions of dollars in Sumatran rhino propagation programs in range-countries, in collaboration with the governments of Indonesia and Malaysia.

United States. In 1997, seven imported rhinos were held in US zoos. In a true spirit of cooperation, the Bronx and Los Angeles Zoos sent their female rhinos to live with the only male rhino (Ipuh - Studbook [SB]# 28) at the Cincinnati Zoo & Botanical Garden for one last effort to breed this species. After years of extensive research, the first Sumatran rhino calf was bred and born in captivity (Andalas – male, SB # 42). This birth, from sire Ipuh and dam Emi (SB # 29), was the first captive Sumatran rhino birth in 112 years. A second birth quickly followed (Suci – female, SB # 43) in 2004. Male offspring Harapan (SB # 44) was born in 2007. Unfortunately, in 2009, breeding female Emi died from liver failure due to hemacrhomatosis (GMPB 2010). Suci and Ipuh remain at the Cincinnati Zoo & Botanical Garden.

Male offspring Harapan is housed at White Oak Conservation Center, a 7,400-acre facility in north Florida and southeast Georgia. White Oak presently holds four of the five rhino species (black, white, Indian and Sumatran) in large, naturalistic enclosures. White Oak is a founding member of the International Rhino Foundation (IRF), hosts the IRF's program office and provides administrative support.

Indonesia. The Sumatran Rhino Sanctuary (SRS) in Way Kambas National Park, Sumatra encloses 100 hectares (247 acres) of native rainforest habitat for propagation, research and education purposes. The SRS was developed in 1998. Facilities include a large, fenced enclosure of native forest for each of five rhinos; a large, fenced central breeding area with observation posts; a guard post; a small visitor and education center; and very basic barracks, meeting rooms, and veterinary facilities.

For many years the SRS held only non-reproductive rhinos, but today three of the five rhinos in the SRS are reproductively viable. With the advent of the methodologies developed by the Cincinnati Zoo facilitating reliable reproduction, the addition of two rescued, young, healthy females into the SRS population, and the transfer of Cincinnati Zoo-born male Andalas to the SRS in February 2007, the Sanctuary is poised for successful rhino breeding. Late last year Andalas and Ratu (SB # 46), a young, healthy female who was rescued in 2005, bred for the first time and Ratu eventually became pregnant after their third mating. Unfortunately she later miscarried, but this first pregnancy is still considered a major success. Ratu and Andalas have resumed breeding, and the SRS is continuing with efforts to achieve another pregnancy. Andalas' mother Emi (SB #29), who died in 2009, lost a number of pregnancies early in gestation before successfully carrying a pregnancy to term, and extensive reproductive research carried out in Cincinnati will be used to help Ratu sustain her next pregnancy. A second female, Rosa (SB # 45), was also rescued in 2005, but has a number of behavioral idiosyncrasies which have prevented her from successfully breeding with the resident SRS males.

***Malaysia*.** Two rhinos are held at a facility in Tabin Wildlife Reserve in Sabah, Malaysia: Tam (SB # 47), an adult male (~21 years old) who wandered out of the forest in April 2008, and a post-reproductive female of unknown age, Gelogob (SB #40, who was captured in 1994. Reproductive assessments on both animals were performed in November 2009 through a collaboration of the Leibnitz Institute for Zoo and Wildlife Research (Berlin), Research Institute for Wildlife Ecology (Vienna), and Sabah Wildlife Department.

A small amount of sperm (21 ml) was collected from Tam, cryopreserved and retained by Sabah Wildlife Department. Concentrations of viable sperm were judged too low for use via artificial insemination or *in vitro* fertilization. There appear to be good prospects for better quality sperm collection in the future. Gelogob was examined using trans-rectal ultrasound without chemical restraint. She is presumed acyclic and reproductively senescent; pregnancy from natural mating or artificial insemination is highly unlikely.

The Malaysian government has committed to a Rhino Rescue Program in Sabah, with the intention that any remaining scattered and isolated rhinos that can be located and caught from outside Tabin and Danum will be translocated to a fenced sanctuary inside Tabin. Two rhinos are targeted for capture within the next year.

Sumatran Rhino Global Propagation and Management Board

The current captive Sumatran rhino population is overseen by the Sumatran Rhino Global Propagation and Management Board (GMPB), which was established in 2005. The GMPB is comprised of NGOs, governments, private donors, zoos and other international rhino conservation organizations like the International Rhino Foundation, the Borneo Rhino Alliance and the Asian Rhino Project of Australia, all of which have invested enormous resources and effort into saving this species. This group includes representatives from range-states, rhino experts, key supporters, and technical advisors who can be called in to assist with specific issues.

The mission of the GMPB is to make management recommendations that will optimize the chances for successful propagation from all Sumatran rhinos in captivity. The tasks of the GMPB are: (1) to recommend and decide on the management of the global Sumatran rhino captive population as a truly global population to maximize the options for reproduction and to improve its vitality in a global Sumatran rhino propagation program; (2) to prepare and facilitate exchange of animals between all locations if indicated for the purpose of the program; and (3) to facilitate exchange of experience and transfer of knowledge and technology for the benefit of the species.

2010 GMPB Meeting Summary. In February 2010 the GMPB met in Bogor, Indonesia to develop a proactive strategy to address recent changes in the captive population (i.e., the loss of the only breeding female) and to move the captive population towards optimally supporting the wild population. The main questions discussed were: (1) How does the GMPB ensure that the captive population contributes to the wild population and what is needed to make that happen? (2) What are the steps needed to get to the point where the Sumatran rhino can be managed using a meta-population management strategy incorporating the captive and wild population? (3) What are the individual animal recommendations or population needs?

This paper focuses on the third point, and in particular, whether the population in captivity can persist without two important changes: (a) a shift to a truly global management system and (2) the importation of new genetic material to decrease its risk of extinction and enhance its viability.

Two major issues emerged during the population discussions at the 2010 GMPB meeting: (1) whether it would be deleterious to breed the two subspecies together (*Dicerorhinus sumatrensis sumatrensis* [Sumatra] and *Dicerorhinos sumatrensis harrisoni* [Sabah])[1]; and (2) that progress with producing a calf is not moving ahead as quickly as hoped in Indonesia. At the meeting, the discussion to return Ipuh to Indonesia to breed with Ratu and Rosa was re-opened. The discussion was then moved to focus on the underlying need, rather than the position. The position is that Ipuh (whose genes are already represented in his male offspring Andalas), should be moved from Cincinnati Zoo to the SRS; the underlying need is that the SRS needs a viable male to produce offspring. With that, the discussions moved away from the position of moving Ipuh to examine what kinds of actions or strategies could address the need for the broader question: what will it take to ensure that the captive population is viable long-term? The group agreed that the primary need is that more genetic diversity in the population, accompanied by a better understanding of population dynamics, is needed.

An informal analysis suggested that if all of the animals capable of reproduction bred under optimal (and hypothetical) conditions, 17 animals could be "on the ground" by 2020. However, this scenario would still not be enough to make the captive population a substantial insurance population for the wild population nor reduce its risk of extinction.

With that goal in mind, the GMPB constructed a hypothetical model including existing animals and locations, and then adding additional animals to the global population (Figure 1). The group agreed that the best option would be adding two new males and one new female to the global population. This scenario had the potential to substantially improve the breeding options for the captive population and likely would add significantly to population persistence should breeding be successful. Optimally, "Tam" from Sabah would also be used as a reproductive male, but the model at that time assumed that he would not be included in the breeding population. Until the subspecies issue is resolved, Sabah has very limited options. Females Bina and Gelogob are thought to be non-reproductive. Since the January 2010 meeting, the Sabah GMPB representatives have used molecular genetics techniques to sort out the subspecies issue. Their conclusion was that there is not enough genetic separation between the two subspecies to merit keeping the captive populations as distinct breeding units, especially given the very low population numbers. These results will be discussed at the February 2011 GMPB meeting in Kota Kinabalu, Sabah.

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[1] The IUCN Asian Rhino Specialist Group recommended at its January 2009 meeting that: (1) where populations are seen to be declining, or there is an absence of breeding, that it is necessary to consider all Sumatran rhinos as members of a single global population; and (2) individual animals and their germplasm may be exchanged between participating countries for breeding purposes consider a formal dialogue between the Governments of Indonesia and Malaysia (Federal and Sabah) and the United States on a possible Sumatran rhino exchange program to strengthen the Sumatran rhino populations.

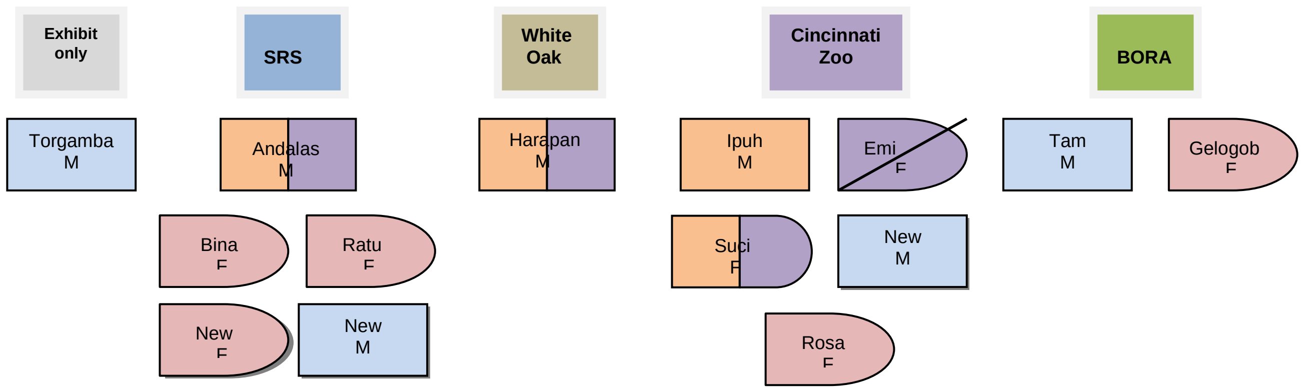

Figure 1. Hypothetical captive Sumatran rhino population with the addition of a new wild-caught male and female in Sumatra and one new wild-caught male, plus moving Rosa to Cincinnati to address behavioral issues (GMPB 2010).

The purpose of this paper is to present an analysis of a range of scenarios for the captive population, as recommended by the GMPB, and in support of the recommendation to add more wild-caught animals to the population. Appendix I shows the available options for each animal in the captive population as discussed at the January 2010 GMPB meeting. The benefits and risks of those options are included as Appendix 2.

ANALYSIS

Population Viability Analysis

As part of the research to substantiate this recommendation, a Population Viability Analysis (PVA) was carried out to analyze the potential persistence of the captive population of Sumatran rhinos. PVA is a computer modeling tool that can be used to assess the current and future risk of population decline and extinction. Many factors and processes affect population persistence: variation in the environment (such as weather, food supplies, and predation), genetic changes in the population (such as genetic drift, inbreeding, and response to natural selection), catastrophic effects (such as disease epidemics, floods, and droughts), the chance results of the probabilistic events in the lives of individuals (such as breeding success and survival), and the interactions among these factors (Gilpin and Soulé 1986). All of these factors and processes, as well as others, are often considered for PVAs on wild populations. However, the two factors that are often of the most interest for PVAs on captive populations are stochasticity in the lives of individuals and genetic changes in the population, because the influence of environmental variation and catastrophes are often thought to be reduced in a captive setting. Exploring the impact of these factors on a population though PVA modeling can help us understand and predict the probability of population persistence.

The software package VORTEX (v9.98; Lacy 1993) was used to develop a PVA for the global population of captive Sumatran rhinos. VORTEX simulates the effects of deterministic forces on a population as well as demographic, environmental, and genetic stochastic events. The VORTEX model is individual-based and simulates a population by stepping through a series of discrete events that describe the typical life cycle of sexually reproducing, diploid organisms. Model events, or parameters, occur according to defined probabilities (constant or random variables that follow specified distributions). Thus, each run (iteration) of the model provides a unique result. By running the model hundreds of times, it is possible to describe the range of probable outcomes of a particular parameter set. 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 = 47). 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.

Global Population Overview:
The International Sumatran Rhinoceros Studbook currently tracks 10 living animals (five males and five females) distributed across Sumatra, Malaysia, and the US. Two animals (Studbook [SB] #4 and 32) are considered post-reproductive and were effectively removed from the potential breeding population. After those exclusions, eight animals (four males, four females) remained in the population that was used for PVA modeling (male Ipuh - SB# 28, female Gelogob – SB# 40, male Andalas - SB#42, female Suci – SB # 43, male Harapan – SB #44, female Rosa – SB #45, female Ratu – SB #46, and Tam – SB #47).

Settings
Number of Populations:
Two population management scenarios were considered. For the first scenario, the global population of captive Sumatran rhinos was considered to be a single population. This scenario predicted the effects of intensely managing the population on a global scale, with unrestricted transfers among regional subpopulations. For the second scenario, the global population was divided into three regional groups: three animals (male Ipuh - SB# 28, female Suci – SB #43, male Harapan – SB #44) currently living in the United States were included in Population 1, three animals (male Andalas - SB#42, female Rosa – SB #45, and female Ratu – SB #46) currently living in the SRS were included in Population 2, and two animals (female Gelogob - SB# 40 and male Tam – SB #47) housed singly in Malaysia were included in Population 3. This scenario predicted the effects of intensely managing subpopulations on a regional scale, with reduced transfers among regional subpopulations.

Definition of extinction:
Extinction was defined as only one sex remaining in the population.

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, with demographic and genetic summaries reported at 25, 50, and 100 year intervals. Given that Sumatran rhinos can live

up to ~40 years of age, a projection out to 100 years was necessary to capture results across multiple generations. Although current conservation management will likely be concerned with shorter time frames, for long-lived species like the Sumatran rhino the impacts of population processes may not be evident until many years after the onset of effect. Thus, modeling population trends several generations into the future provided valuable information about the long-term impacts of current population parameters and proposed conservation efforts.

Species Description

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).

Reproductive System

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 6-7 years of age and males are thought to sexually mature at ~10 years of age. Sumatran rhino gestation is ~15-16 months. Thus, to conform to the manner in which VORTEX defines reproduction, the age of first reproduction for females was set to 7 and the age of first reproduction for males was set to 11.

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 40 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, as the studbook indicates that only four captive-born calves have ever been produced. Still, three of those calves were produced in 2001, 2004, and 2007 (i.e., 3 years apart) by a single female. Additionally, when captive reproduction does occur some females could lose their offspring within 3 years of birth, coming into estrus soon afterwards and subsequently increasing the yearly percent of females breeding. Two values for percent females breeding were modeled: 33% and 20%.

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. The data that are available suggest adults experience very low rates of mortality, which are likely comparable to mortality rates observed in other captive rhino populations. Yearly adult mortality ranges from 1-7% for captive southern white rhinos (*Ceratotherium simum simum*), 3-7% for captive Indian rhinos (*Rhinoceros unicornis*), 1-14% for captive eastern black rhinos (*Diceros bicornis michaeli*), and 1-17% for captive southern black rhinos (*Diceros bicornis minor*). Based on this information, yearly adult mortality for Sumatran rhinos was set at 5%.

Predicting mortality during the first year of life is difficult for Sumatran rhinos, because only four rhinos in the International Studbook have been born and all lived through their first year of life. First-year mortality is 17% for captive southern white rhinos (*Ceratotherium simum simum*), 28% for captive Indian rhinos (*Rhinoceros unicornis*), 27% for captive eastern black rhinos (*Diceros bicornis michaeli*), and 16% for captive southern black rhinos (*Diceros bicornis minor*). Two values for first year mortality were modeled: 15% and 25%.

	Low First Year Morality	High First Year Mortality
Morality from Age 0 to 1	15%	25%
Mortality from Age 1 to 40	5%	5%
% Surviving to Age 40	11%	10%

Carrying Capacity
A carrying capacity of 300 animals (100 per geographic region) was imposed on the model. Future carrying capacities for the captive population are currently unclear, but given current population parameters a capacity of 300 animals was unlikely to significantly impact general projection results. Dramatically smaller capacities could greatly influence

projections, however, and models should be re-run if future capacities are determined to be small.

Transfer Rates

Transfer rates were specified for scenarios that modeled the global population of captive Sumatran rhinos as three regional subpopulations. 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, three yearly transfer rates between all combinations of subpopulations were modeled: 0%, 1%, and 3%. The model restricted transfers to younger, reproductive animals 10-30 years of age, and assumed that no animals suffered mortality during transfer.

Genetic Management and Breeding Pair Selection

Although VORTEX can model the genetic management of a captive population by applying a breeding pair selection scheme that minimizes average kinship, genetic management was not applied to the global population of captive Sumatran rhinos. 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. During this stage of captive breeding, any successful breeding pairs are encouraged to help bolster the chances of population persistence. 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.

Summary of Scenario Parameters

Model Input Parameter	Baseline Value
# of populations	1; 3
inbreeding depression included?	yes
environmental variation included?	no
breeding system	polygamous
age of first reproduction (♂ / ♀)	11 / 7
maximum age of reproduction	40
annual % adult females breeding	33; 20
% males in breeding pool	100
litter size	1
offspring sex ratio	0.5
% annual mortality	
0-1 years	15; 25
1-40 years	5
initial population size	8 breeding animals
carrying capacity	300 total (100 per subpopulation)
% transfer rates	0; 1; 3
breeding pair selection	random
genetic management	avoid close inbreeding

Four additional scenarios of interest also were modeled: 1) importing an additional pair of wild-caught rhinos (one male and one female) into the captive subpopulation in Sumatra, 2) importing one additional wild-caught male into the captive subpopulation in the US, 3) moving Rosa (SB#45) from Sumatra to the US, and 4) the combination of scenarios 1,2, and 3. The transfer of additional rhinos to the US is of interest because three of the four captive births recorded in the International Sumatran Rhinoceros Studbook occurred in the US, but the US does not currently have a viable breeding pair of rhinos (the only US female is closely related to both US males and one of the males in Sumatra). The four additional scenarios of interest were modeled under only two of the 16 possible parameter sets described in the previous paragraph. The additional scenarios were modeled under the most optimistic parameter sets for the two management strategies investigated: managing the global population of captive Sumatran rhinos as a single population vs. managing subpopulations on a regional scale with reduced transfers among regional subpopulations.

Results

Effects of Management Structure:

Results suggested that 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 subpopulations. When managed as a single population, the probabilities of extinction within the next 25 years for captive Sumatran rhinos ranged from 6-17% (Table 1). When managed as separate regional subpopulations, the probabilities of extinction of all subpopulations within the next 25 years ranged from 26-41% (Table 2). Probabilities of extinction for a given subpopulation ranged from 57-93% over the same time frame (Table 2), with the subpopulations in the US and Malaysia at the highest risks of extinction. Long-term projections further highlighted the benefit of managing captive Sumatran rhinos as a single population: over the next 100 years extinction probabilities for a single population ranged from 31-95%, while extinction probabilities for separately managed subpopulations ranged from 93-100% (Tables 1 and 2). These results are consistent with what is known and expected about the effects of small population size. As population size declines, extinction risk increases due to demographic instability and the deleterious effects of inbreeding on reproduction and survival (Gilpin and Soulé 1986; Caughley 1994). Thus, a single, larger population will have a lower risk of extinction when compared to several smaller, fragmented populations with reduced migration (or transfer) rates.

Effects of Biological Variables:

Due to the paucity of biological data on Sumatran rhinos, ranges of reproductive success and mortality were tested to determine how sensitive the probability of population persistence was to these factors. As expected, lower rates of reproductive success (measured as the % of females breeding in a given year) and higher rates of first-year mortality resulted in higher probabilities of extinction (Tables 1 and 2). However, decreasing reproductive success had a noticeably greater impact on probability of extinction than increasing mortality. For example, if captive Sumatran rhinos were managed as a single population, the impact of increasing first-year mortality from 15% to

25% increased extinction risk over the next 100 years by 9-15%, while decreasing the % females breeding from 33% to 20% increased extinction risk over the same time frame by 49-55% (Table 1).

Effects of Transfer Rate Among Subpopulations:

If the global population of captive Sumatran rhinos is managed as separate subpopulations, a restricted rate of animal transfers between subpopulations is expected. VORTEX models transfers (dispersals, migrations, etc.) on a yearly basis, but it is unlikely that regional subpopulations would exchange animals annually due to the logistics and costs associated with moving rhinos long distances. Still, to model low levels of exchange between subpopulations, three yearly transfer rates between all combinations of subpopulations were modeled: 0%, 1%, and 3%. When single subpopulations were considered, increasing the transfer rate among subpopulations had small, varying impacts on subpopulation extinction probabilities (Table 2): in some cases extinction probability decreased slightly, in other cases it increased slightly. In general, increasing transfers among subpopulations slightly decreased the extinction risks of the US and Malaysian subpopulations while slightly increasing the extinction risk of the Sumatran subpopulation. All three transfer rates produced very similar results when the extinction risk of the total population was considered (Table 2), indicating that transfer rates up to 3% do not notably decrease the probability of the entire captive population becoming extinct. However, it is important to note that because the US subpopulation does not currently have a viable breeding pair of rhinos, that subpopulation will ultimately go extinct without additional imports.

Impact of Importing an Additional Pair of Wild-Caught Rhinos into the Captive Subpopulation in Sumatra:

Given the demographic instability of the small, global population of captive Sumatran rhinos, the impact of importing an additional pair of wild-caught rhinos (one male and one female) into the population is of interest. For the most optimistic scenario in which all captive animals were managed as a single population (33% of females breeding; 15% first-year mortality), importing two additional wild-caught rhinos decreased the extinction probability of the population from 6% to 1% over the next 25 years (Tables 1 and 3). Over the next 100 years, the extinction probability dropped from 31% to 12% (Tables 1 and 3). If regional subpopulations were managed with no transfers, importing two additional wild-caught rhinos into the Sumatran subpopulation decreased the extinction risk of that subpopulation from 57% to 15% over the next 25 years (Tables 2 and 4). Over the next 100 years, the extinction risk of the Sumatran subpopulation dropped from 94% to 54% (Tables 2 and 4).

Impact of Importing an Additional Wild-Caught Male Rhino into the Captive Subpopulation in the US:

The import of an additional wild-caught male into the US subpopulation is of interest given that three of the four captive births recorded in the International Sumatran Rhinoceros Studbook have occurred in the US, but the US does not currently have a viable breeding pair of rhinos (the only US female is closely related to both US males). For the most optimistic scenario in which all captive animals were managed as a single population (33% of females breeding; 15% first-year mortality), importing an additional wild-caught male decreased the extinction probability of the population from 6% to 2% over the next 25 years (Tables 1 and 5). Over the next 100 years, the extinction probability dropped from 31% to 22% (Tables 1 and 5). If regional subpopulations were managed with no transfers, importing an additional wild-caught male into the US subpopulation decreased the extinction risk of that subpopulation from 89% to 55% over the next 25 years (Tables 2 and 6). Over the next 100 years, the extinction risk of the US subpopulation stayed nearly the same, dropping only from 100% to 99% (Tables 2 and 6).

Impact of Transferring Female Rosa (SB #45) from Sumatra to the US:

The transfer of female Rosa (SB #45) from Sumatra to the US if of interest given that three of the four captive births recorded in the International Sumatran Rhinoceros Studbook have occurred in the US. Thus, it is possible that transferring female Rosa (SB#45) to the US could help to address her behavioral issues, thereby increasing her chances of successfully reproducing. For the most optimistic scenario in which all captive animals were managed as a single population (33% of females breeding; 15% first-year mortality), moving Rosa from Sumatra to the US had essentially no impact on overall extinction risk (Tables 1 and 7). Because all animals were being managed together in that scenario, the regional location of animals effectively made no difference. If regional subpopulations were managed with no transfers, transferring Rosa from Sumatra to the US decreased the 25-year extinction risk of the US subpopulation from 89% to 65% and increased the 25-year extinction risk of the Sumatran subpopulation from 57% to 76% (Tables 2 and 8). Thus, the increase in the probability that the US subpopulation persisted for the next 25 years was greater than the increase in the extinction risk experienced by the Sumatran subpopulation (difference of 24% vs. 19%). Over the long-term, however, the risk of extinction for the US subpopulation remained nearly unchanged while a noticeable increase in the extinction risk of the Sumatran subpopulation persisted (100-year extinction risk increased from 94% to 100% with the transfer of Rosa).

Impact of Combing All Previous Scenarios:

The final modeled scenario combined all previous scenarios: importing an additional pair of wild-caught rhinos into the captive Sumatran subpopulation, importing an additional wild-caught male into the captive US subpopulation, and moving Rosa (SB #45) from Sumatra to the US. For the most optimistic scenario in which all captive animals were managed as a single population (33% of females breeding; 15% first-year mortality), combining all previous scenarios decreased the extinction probability of the population from 6% to 0% over the next 25 years (Tables 1 and 9). Over the next 100 years, the extinction probability dropped from 31% to 11% (Tables 1 and 9). If regional subpopulations were managed with no transfers, combining all previous scenarios decreased the extinction risk of all subpopulations except the one in Malaysia over the next 25 years: the extinction risk of the US subpopulation decreased from 89% to 28%, the extinction risk of the Sumatran subpopulation decreased from 57% to 30%, and the extinction risk of the Malaysian subpopulation remained at approximately 80% (Tables 2 and 10). A similar trend was observed over the next 100 years: the extinction risk of the US subpopulation decreased from 100% to 80%, the extinction risk of the Sumatran subpopulation decreased from 94% to 79%, and the extinction risk of the Malaysian subpopulation remained at 100% (Tables 2 and 10).

Discussion

The VORTEX modeling and projections presented here are based on biological parameters that are very poorly defined for the Sumatran rhino. Thus, a series of scenarios was designed to predict the future persistence of the global population of captive Sumatran rhinos across a range of plausible parameters. Although care was taken to incorporate the information that is available on Sumatran rhino biology, as well as previous PVA work on wild Sumatran rhinos and information gleaned from other rhino species, projections should be considered to be approximate guidelines of future population persistence.

Both demography and genetics play a role in population viability. However, for the current captive population of Sumatran rhinos, the gene diversity retained by the population experienced smaller fluctuations across modeled scenarios than did extinction risk. In other words, while the modeled scenarios demonstrated a range in extinction risks for the population, the gene diversity retained by populations that managed to persist remained more constant. This indicates that, unless the demographic outlook of the captive population can be significantly improved in terms of population size and growth rate, a focus should be placed on improving extinction risk over gene diversity retention.

The two biological parameters that were varied across scenarios were reproductive success, measured as the % of females breeding in a given year, and first-year mortality. As expected, lower rates of reproductive success and higher rates of first-year mortality resulted in higher probabilities of extinction (Tables 1 and 2). However, results also suggested that extinction risk was more sensitive to reproductive success than the first-year mortality of offspring. All four of the captive-born Sumatran rhinos in the International Studbook lived through their first year of life, which makes the estimation of first-year mortality difficult. However, other rhino studbooks suggest that first-year mortalities for other captive species range from 16% to 28%. Thus, the range of first-year mortalities modeled here, 15% to 25%, adequately covers the range exhibited across other species. Unless first-year mortality is found to be significantly higher for the Sumatran rhino, the extinction risk of the population can be more effectively decreased by focusing on increasing the number of breeding females.

All modeled scenarios demonstrated that the global population of captive Sumatran rhinos has a moderate to high risk of extinction over the long-term (Tables 1 and 2). Extinction risk notably declined if all captive animals could be managed as a single population vs. managed as regional subpopulations with limited transfers between geographic areas. This result was primarily driven by the low numbers of captive Sumatran rhinos that currently exist. The smaller a population, the more demographically unstable that population is due to both chance events that impact the survival and reproduction of individual animals and random fluctuations in the sex ratio of the population. By managing all captive Sumatran rhinos as a single population, the increase in population size compared to the sizes of regional subpopulations reduced the impact of these processes which decreased extinction risk. However, given the costs and risks associated with moving rhinos long distances, it is important to note that it would be extremely difficult, if not impossible, to effectively manage these widely distributed captive animals as a single population. Furthermore, results indicate that low rates of transfer among subpopulations

(1-3% per year) do not improve the extinction risk of the metapopulation over either the short or long-term. This suggests that the current location of animals and the possibility of future transfers among geographic regions should be carefully evaluated.

Results suggested that importing an additional pair of wild-caught rhinos into the captive Sumatran subpopulation would have a greater impact on extinction risk than on gene diversity retention (Tables 3 and 4). Again, this result was primarily driven by population size. The current size of both the entire captive population and the Sumatran subpopulation is so small, adding only two additional individuals notably impacts the degree to which chance events affect population demography and extinction risk. Although the effect was not as great, importing two additional wild-caught rhinos did also improve both short and long-term gene diversity retention. Projected gene diversity retention over the next 25 years increased from an average of 82% to 86% if all captive animals were managed as a single population (33% of females breeding; 15% first-year mortality). If regional subpopulations were managed with no transfers, gene diversity in the Sumatran subpopulation increased over the same time frame from an average of 73% to 79%. Over the next 100 years, gene diversity retention increased from 75 to 79% if all captive animals were managed as a single population and gene diversity retention in the Sumatran subpopulation increased from 61% to 72% if regional subpopulations were managed with no transfers.

Conservation breeding programs often aim to retain 90% of initial gene diversity, to maintain the potential for adaptation and minimize the deleterious consequences of inbreeding (Soulé 1986). Gene diversity across the entire captive population is currently only ~90%, and gene diversity is predicted to further decline across all tested scenarios. In general, more gene diversity was retained across scenarios that exhibited lower extinction probabilities. The most gene diversity was retained if three additional wild-caught animals were imported, all captive animals could be managed as a single population, reproduction was maximized, and first-year mortality was minimized.

The transfer of female Rosa (SB #45) from Sumatra to the US was considered because three of the four captive births recorded in the International Sumatran Rhinoceros Studbook have occurred in the US and it is possible that transferring female #45 to the US could address her behavioral pathologies and increase her chances of successfully reproducing, while giving the US subpopulation a viable pair of breeding rhinos. If regional subpopulations are separately managed with no transfers, transferring Rosa from Sumatra to the US was projected to provide an overall advantage in terms of extinction risk over the short-term: the increase in the probability that the US subpopulation persisted for the next 25 years was greater than the increase in the extinction risk experienced by the Sumatran subpopulation (Table 6; difference of 24% vs. 19%). Over the long-term, however, the risk of extinction for the US subpopulation remained nearly unchanged while a noticeable increase in the extinction risk of the Sumatran subpopulation persisted; the 100-year extinction risk increased from 94% to 100% with the transfer of Rosa (Table 6). Still, one could argue that a 94% extinction risk is already prohibitively high and increasing that risk further over the next 100 years might be justifiable given the potential for shorter-term gains in terms of decreasing the extinction risk of the US subpopulation and increasing the potential for reproduction.

Finally, a scenario that combined all previously discussed scenarios was considered. This scenario had the biggest positive impacts on the viability of the global population of captive Sumatran rhinos, as it combined importing a pair of wild-caught rhinos into the Sumatran subpopulation, importing a wild-caught male into the US subpopulation, and transferring female #45 to the US. If all captive animals were managed as a single population (33% of females breeding; 15% first-year mortality), this combination of scenarios eliminated the risk of population extinction over the next 25 years and decreased extinction risk by 20% over the next 100 years (Tables 1 and 9). If regional subpopulations were managed with no transfers, this combination of scenarios decreased the extinction risks for the Sumatran and US subpopulations by 61% and 27%, respectively (Tables 2 and 10). The extinction risk for the Malaysian subpopulation effectively remained unchanged, because that subpopulation did not benefit from additional imports.

CONCLUSION

The management of the captive Sumatran rhino population is scientifically and politically challenging, involving governments of Indonesia, Malaysia, the US, as well as a host of international stakeholders, including permitting authorities. The analyses presented in this paper suggest that if the captive population is truly to be part of a holistic strategy for the conservation of the Sumatran rhino, <u>the most important issue at hand is preventing the extinction of the captive population and that maintaining genetic diversity of that population, which was originally the focus when this analysis was begun, is actually secondary</u>.

<u>The most important need is to manage captive Sumatran rhinos as one global population,</u> which has been the mandate of the GMPB and, more recently, the recommendation of the IUCN Asian Rhino Specialist Group. While this strategy also presents many hurdles - in particular, the costs and risks associated with moving rhinos long distances - it nevertheless needs to be immediately implemented to prevent the population's drift towards extinction. Analyses contained in this paper also demonstrate the need to increase the population size as expeditiously as possible.

In January 2010, the GMPB agreed that adding two new wild-caught females and one new wild-caught male had the potential to substantially improve the breeding options for the captive population and likely would add significantly to genetic variability should breeding be successful. The present analyses suggest that, more importantly, <u>adding animals to the global population is essential for its long term persistence</u>. For the global population, adding a new male and female to the Sumatra subpopulation lowers the 100-year probability of extinction from 31%to 12%. Under a global management scenario, importing an additional wild-caught male into the US subpopulation decreases the probability of extinction of the entire population to 2% over the next 25 years, and to 22% over the next 100 years. Of note, because the US subpopulation does not currently have a viable breeding pair, without additional imports that subpopulation will ultimately go extinct. This has additional ramifications - the largest supporters of the Sumatra program are US zoos and the loss of Sumatran rhino ambassadors will likely affect funding for that program. The US subpopulation also provides a small measure of genetic insurance for the Indonesian and Malaysian subpopulations.

The management option with the most potential positive impact combines adding new wild-caught animals to both the Sumatra and the US subpopulations and transferring female Rosa to the US. This option has the potential to eliminate the risk of population extinction over the next 25 years, and by 20% over the next 100 years[2]. In combination with other methods, such as successfully developing artificial insemination and other artificial reproductive technologies, the case can be made that this strategy buys much-needed time for the captive population, with minimal impact on the wild population. Additionally, transferring Rosa (SB #45) from Sumatra to the US could allow her behavioral pathologies to be addressed under a different husbandry regime and could increase chances of this founder female successfully reproducing. This transfer has no impact on overall population extinction risk and also frees up space for a new female at the SRS.

There is an urgent need for decisive management action for the captive population of Sumatran rhinos. Acting on this last management recommendation as soon as possible will 'buy' important time for the captive population. Concurrently, other methodologies to improve management need to be immediately developed, which may include artificial reproduction techniques. Other creative management strategies discussed by the GMPB should also begin testing immediately, including temporarily bringing wild rhinos into captivity for gamete collection and releasing captive animals into the wild short-term for natural breeding while under close monitoring.

The authors have conducted these analyses with the objective of acting in the best interest of the species and in consideration of the the acceptability of these recommendations within the conservation community. We urge the governments of Indonesia and Malaysia to seriously consider these recommendations, and that those governments begin a formal dialogue on a possible Sumatran rhino exchange program, along with the US government, to strengthen the global Sumatran rhino population. We also invite other members of the international community, including donor states, the private sector, the corporate sector, academic and scientific institutions, to provide effective and united support, including funding, to assist these efforts.

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[2] The extinction risk for the Malaysian subpopulation effectively remains unchanged, because that subpopulation did not benefit from additional imports.

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Table Legend

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.

Table 1: VORTEX results for managing the global population of Sumatran rhinos as a single population

% females breeding	% first-year mortality	25 Years			50 Years			100 Years		
		PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
33	15	0.06	17 ± 8	82 ± 6	0.15	29 ± 19	78 ± 7	0.31	78 ± 64	75 ± 10
33	25	0.06	14 ± 7	82 ± 5	0.20	20 ± 14	77 ± 8	0.46	41 ± 36	72 ± 11
20	15	0.14	9 ± 4	80 ± 6	0.44	9 ± 6	73 ± 10	0.86	10 ± 8	64 ± 15
20	25	0.17	8 ± 4	79 ± 6	0.55	7 ± 5	70 ± 11	0.95	6 ± 4	62 ± 16

Table 2: VORTEX results for managing the global population of Sumatran rhinos as regional subpopulations

% transfer rate	% females breeding	% first-year mortality		25 Years			50 Years			100 Years		
				PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
0	33	15	US	0.89	2 ± 1	63 ± 7	1.00	-	-	1.00	-	-
			SRS	0.57	7 ± 4	73 ± 7	0.82	10 ± 7	68 ± 10	0.94	19 ± 19	61 ± 16
			Malaysia	0.80	3 ± 1	65 ± 8	0.99	2 ± 0	61 ± 7	1.00	-	-
			Total	0.27	7 ± 4	79 ± 7	0.80	9 ± 7	68 ± 10	0.94	19 ± 19	61 ± 16
0	33	25	US	0.88	2 ± 1	64 ± 6	1.00	-	-	1.00	-	-
			SRS	0.57	6 ± 3	72 ± 6	0.85	10 ± 7	69 ± 8	0.97	15 ± 18	61 ± 14
			Malaysia	0.83	3 ± 1	65 ± 8	0.99	2 ± 1	61 ± 13	1.00	na	na
			Total	0.28	6 ± 3	79 ± 7	0.84	9 ± 7	69 ± 8	0.97	15 ± 18	61 ± 14
0	20	15	US	0.86	2 ± 1	63 ± 6	1.00	-	-	1.00	-	-
			SRS	0.67	5 ± 2	72 ± 7	0.94	6 ± 3	67 ± 12	1.00	-	-
			Malaysia	0.91	3 ± 1	66 ± 8	1.00	-	-	1.00	-	-
			Total	0.36	5 ± 3	78 ± 7	0.93	5 ± 3	68 ± 12	1.00	-	-
0	20	25	US	0.88	2 ± 1	63 ± 6	1.00	-	-	1.00	-	-
			SRS	0.68	4 ± 2	72 ± 6	0.95	4 ± 2	64 ± 11	1.00	-	-
			Malaysia	0.93	3 ± 1	65 ± 9	1.00	-	-	1.00	-	-
			Total	0.41	5 ± 2	78 ± 7	0.95	4 ± 2	65 ± 12	1.00	-	-
1	33	15	US	0.87	3 ± 2	65 ± 8	0.99	4 ± 3	69 ± 8	1.00	-	-
			SRS	0.58	6 ± 4	73 ± 7	0.83	10 ± 9	68 ± 12	0.95	29 ± 31	67 ± 14
			Malaysia	0.81	4 ± 2	70 ± 8	0.94	6 ± 4	70 ± 8	0.99	11 ± 8	67 ± 10
			Total	0.26	7 ± 4	79 ± 6	0.75	10 ± 9	70 ± 11	0.94	27 ± 31	67 ± 12
1	33	25	US	0.86	3 ± 1	66 ± 8	0.99	5 ± 3	62 ± 14	1.00	-	-
			SRS	0.61	5 ± 3	73 ± 7	0.87	8 ± 6	68 ± 11	0.97	22 ± 26	66 ± 12
			Malaysia	0.83	4 ± 2	70 ± 8	0.96	7 ± 6	65 ± 12	0.99	24 ± 19	70 ± 12
			Total	0.28	6 ± 4	78 ± 7	0.82	9 ± 7	70 ± 10	0.97	23 ± 25	67 ± 11
1	20	15	US	0.89	3 ± 1	66 ± 8	1.00	-	-	1.00	-	-
			SRS	0.67	4 ± 2	73 ± 7	0.94	5 ± 3	66 ± 11	1.00	-	-
			Malaysia	0.91	3 ± 1	68 ± 9	0.99	4 ± 2	64 ± 10	1.00	-	-
			Total	0.36	5 ± 3	78 ± 6	0.91	4 ± 3	67 ± 10	1.00	-	-
1	20	25	US	0.89	2 ± 1	64 ± 7	1.00	-	-	1.00	-	-
			SRS	0.70	4 ± 2	72 ± 7	0.97	3 ± 1	65 ± 10	1.00	-	-

% transfer rate	% females breeding	% first-year mortality		25 Years			50 Years			100 Years		
				PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
			Malaysia	0.91	3 ± 1	69 ± 8	0.99	3 ± 1	68 ± 5	1.00	-	-
			Total	0.40	4 ± 2	77 ± 7	0.95	3 ± 1	67 ± 8	1.00	-	-
3	33	15	US	0.83	3 ± 2	68 ± 8	0.96	6 ± 4	65 ± 11	1.00	-	-
			SRS	0.58	6 ± 4	75 ± 7	0.81	10 ± 8	70 ± 9	0.94	33 ± 28	70 ± 10
			Malaysia	0.78	4 ± 2	71 ± 8	0.91	7 ± 6	69 ± 10	0.98	19 ± 21	65 ± 14
			Total	0.27	7 ± 5	79 ± 7	0.70	11 ± 10	72 ± 9	0.93	35 ± 35	69 ± 11
3	33	25	US	0.86	3 ± 1	66 ± 8	0.98	4 ± 3	64 ± 12	1.00	-	-
			SRS	0.59	6 ± 3	74 ± 7	0.86	8 ± 6	68 ± 11	0.98	28 ± 26	62 ± 18
			Malaysia	0.81	4 ± 2	71 ± 7	0.94	7 ± 5	69 ± 10	0.99	15 ± 17	70 ± 8
			Total	0.29	6 ± 4	78 ± 7	0.77	8 ± 7	70 ± 11	0.96	23 ± 26	66 ± 15
3	20	15	US	0.88	3 ± 1	67 ± 7	0.99	3 ± 1	63 ± 8	1.00	-	-
			SRS	0.70	4 ± 2	73 ± 7	0.95	4 ± 3	66 ± 9	1.00	-	-
			Malaysia	0.88	3 ± 1	70 ± 7	0.98	5 ± 3	71 ± 8	1.00	-	-
			Total	0.36	5 ± 3	77 ± 7	0.90	5 ± 3	69 ± 10	1.00	-	-
3	20	25	US	0.88	3 ± 1	67 ± 8	0.99	3 ± 2	62 ± 12	1.00	-	-
			SRS	0.71	4 ± 2	73 ± 7	0.96	4 ± 2	69 ± 8	1.00	-	-
			Malaysia	0.89	3 ± 1	70 ± 7	0.98	3 ± 2	61 ± 12	1.00	-	-
			Total	0.40	5 ± 3	77 ± 7	0.91	4 ± 3	68 ± 10	1.00	-	-

Table 3: VORTEX results for importing 1.1 wild-caught animals into the Sumatran subpopulation; managing the global population of Sumatran rhinos as a single population

% females breeding	% first-year mortality	25 Years			50 Years			100 Years		
		PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
33	15	0.01	23 ± 10	86 ± 4	0.05	40 ± 24	83 ± 7	0.12	113 ± 81	79 ± 8

Table 4: VORTEX results for importing 1.1 wild-caught animals into the Sumatran subpopulation; managing the global population of Sumatran rhinos as regional subpopulations

% transfer rate	% females breeding	% first-year mortality		25 Years			50 Years			100 Years		
				PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
0	33	15	US	0.85	2 ± 1	63 ± 6	1.00	-	-	1.00	-	-
			SRS	0.15	12 ± 7	79 ± 6	0.32	22 ± 17	75 ± 8	0.54	51 ± 35	72 ± 11
			Malaysia	0.81	3 ± 1	65 ± 8	0.99	2 ± 0	67 ± 7	1.00	-	-
			Total	0.06	13 ± 7	84 ± 5	0.31	22 ± 17	76 ± 8	0.54	51 ± 35	72 ± 11

Table 5: VORTEX results for importing 1.0 wild-caught animal into the US subpopulation; managing the global population of Sumatran rhinos as a single population

% females breeding	% first-year mortality	25 Years			50 Years			100 Years		
		PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
33	15	0.02	18 ± 9	84 ± 4	0.09	31 ± 21	80 ± 7	0.22	86 ± 67	77 ± 10

Table 6: VORTEX results for importing 1.0 wild-caught animal into the US subpopulation; managing the global population of Sumatran rhinos as regional subpopulations

% transfer rate	% females breeding	% first-year mortality		25 Years			50 Years			100 Years		
				PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
0	33	15	US	0.55	5 ± 3	70 ± 7	0.86	7 ± 6	63 ± 13	0.99	15 ± 17	65 ± 12
			SRS	0.58	6 ± 3	72 ± 6	0.84	10 ± 7	68 ± 10	0.96	18 ± 20	67 ± 9
			Malaysia	0.83	3 ± 1	67 ± 7	0.99	2 ± 0	66 ± 9	1.00	-	-
			Total	0.17	8 ± 4	81 ± 6	0.71	9 ± 7	69 ± 11	0.95	17 ± 19	66 ± 10

Table 7: VORTEX results for importing moving female #45 from Sumatra to the US; managing the global population of Sumatran rhinos as a single population

% females breeding	% first-year mortality	25 Years			50 Years			100 Years		
		PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
33	15	0.05	17 ± 8	82 ± 5	0.15	29 ± 19	78 ± 8	0.31	80 ± 66	75 ± 10

Table 8: VORTEX results for importing moving female #45 from Sumatra to the US; managing the global population of Sumatran rhinos as regional subpopulations

% transfer rate	% females breeding	% first-year mortality		25 Years			50 Years			100 Years		
				PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
0	33	15	US	0.65	5 ± 2	70 ± 7	0.91	6 ± 5	66 ± 11	0.99	9 ± 6	67 ± 10
			SRS	0.76	4 ± 2	68 ± 6	0.97	2 ± 1	63 ± 8	1.00	-	-
			Malaysia	0.82	3 ± 1	66 ± 8	1.00	-	-	1.00	-	-
			Total	0.28	6 ± 3	79 ± 7	0.87	5 ± 5	68 ± 11	0.99	9 ± 6	67 ± 10

Table 9: VORTEX results for combing all previous scenarios;
managing the global population of Sumatran rhinos as a single population

% females breeding	% first-year mortality	25 Years			50 Years			100 Years		
		PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
33	15	0.00	24 ± 10	88 ± 4	0.03	41 ± 24	84 ± 6	0.11	121 ± 80	81 ± 8

Table 10: VORTEX results for combing all previous scenarios;
managing the global population of Sumatran rhinos as regional subpopulations

% transfer rate	% females breeding	% first-year mortality		25 Years			50 Years			100 Years		
				PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD	PE	N ± SD	GD ± SD
0	33	15	US	0.28	9 ± 5	75 ± 7	0.56	15 ± 11	71 ± 10	0.80	38 ± 31	69 ± 10
			SRS	0.30	9 ± 5	76 ± 7	0.57	16 ± 13	72 ± 10	0.79	45 ± 32	72 ± 10
			Malaysia	0.81	3 ± 1	67 ± 7	1.00	-	-	1.00	-	-
			Total	0.04	15 ± 7	86 ± 4	0.29	19 ± 15	76 ± 9	0.63	46 ± 36	72 ± 10

Appendix I. Potential options for each animal currently in the captive population as of January 2010.

Animal	***Option for Action***	***Notes/Concerns:***
Suci	1. Find unrelated sperm 2. Breed with Ipuh 3. Find unrelated male for natural breeding 4. Breed with Harapan 5. Breed with Andalas * Suci can't wait for 2 years Plan A : find unrelated sperm Plan B: breed with Ipuh to prevent loss of reproductive capacity	- Assume that we will need to justify parent-offspring mating to government of Indonesia - Time consideration; Suci may lose ability to breed altogether if she is not bred soon - There is a risk that mating Ipuh with Suci would present external credibility issues in terms of questions about sound management.
Rosa	1. Change management, decrease intense keeper interaction - socialize with other rhino 2. Breed with Andalas 3. AI with unrelated sperm 4. Release short-term for mating with wild male 5. Breed with Ipuh 6. Get expertise on reversing imprinting	
Ipuh	1. Mate with Rosa 2. Mate with Ratu 3. Bank sperm 4. Use sperm for Rosa 5. Use sperm for Ratu 6. Breed with Suci 7. Breed with new female	- Assume that we will need to justify parent-offspring mating to government of Indonesia - There is a risk that mating Ipuh with Suci would present external credibility issues in terms of questions about sound management.
Andalas	1. Breed with Rosa 2. Breed with Ratu 3. Bank sperm 4. Breed with Bina 5. Breed with new female 6. Continue sperm assessment 7. Breed with Suci	

Animal	*Option for Action*	*Notes/Concerns:*
Harapan	No change because of age	
Ratu	1. Breed with Andalas 2. Breed with new male 3. Breed with Ipuh 4. Use Ipuh's sperm	
Torgamba	1. Use as ambassador animal 2. Compare data with Sabah Tanjung 3. Continue mating with Rosa, Ratu and Bina for behavioral experience. 4. Radio collar testing 5. Use for ecotourism	
Bina	1. Breed with Andalas 2. Breed with Torgamba 3. Use as ambassador animal 4. Radio collar testing 5. Collect gametes 6. Share/compare post-mortem protocol (US and German)	
Tam	1. Collect sperm 2. Find new female in Malaysia	Assumes as of January 2010 that exchange is not possible between Indonesia and Sabah
Gelogob	1. Hormone stimulation 2. Move to Tabin to be placed into Tam 3. Enrich diet to gain weight 4. Regular health assessment to see if underlying cause for weight loss 5. Obtain organ samples post-mortem to study iron deficiency 6. Mate with Tam	

For all options above, there are some obvious decisions:

1. Harapan should remain *status quo* because of his age
2. Andalas and Ratu should be kept together
3. Optimally, Suci should be breed with a new unrelated male or unrelated sperm (possibly Tam)
4. Rosa needs to have management for less intensive keeper interaction to minimize behavioral pathologies. She should be bred with an unrelated male (Andalas or new male) or artificial insemination developed.

APPENDIX II. BENEFITS AND RISKS FOR THE VARIOUS SCENARIOS SUGGESTED FOR EACH RHINO.

a. Move Rosa to Cincinnati Zoo

Potential Benefits:	Potential Risks/Disadvantages:
1. Security 2. Potential for generating more funding from zoos in the US 3. Genetic infusion 4. Conservation networking between countries 5. Could be used as an attention-getting promotion for the whole program 6. Increased capacity building 7. Increase capacity for fundraising from public 8. Space opened up at SRS for other animals 9. Good faith gesture between Cincinnati Zoo and Government of Indonesia 10. Allows addressing Rosa's behavior issues 11. Increases biological information database with data from new animals 12. Increase awareness among government and NGOs 13. Demonstrates that we are managing Sumatran rhinos managing as one population (true metapopulation management)	1. Transport loss 2. May not breed naturally 3. Reduces reproductive options for Andalas 4. Hemosiderosis 5. Local NGOs may express concern about export

b. Move Ipuh to Indonesia (SRS-YABI)

Potential Benefits:	Potential Risks/Disadvantages:
1. Proven breeder 2. High potential for breeding with Ratu and/or Rosa 3. Potential Indonesia donor could be persuaded to pay transport cost	1. Transport loss 2. Older age and potentially blind 3. Genetic variation will be decreased as Ipuh will be over-represented 4. Creates need for new male for Cincinnati Zoo and at SRS. 5. Indonesia donor may only support move, not long-term care/maintenance at SRS. 6. Loss of animal will likely reduce funds from US zoos for Indonesia

programs

7. May limit ability to ability to bring in a new male

c. Bringing New Animals to SRS

Potential Benefits:

1. Demonstrates that we are managing Sumatran rhinos managing as one population (true metapopulation management)
2. Security
3. Infuses captive population with new genes
4. Could be used as an attention-getting promotion for the whole program
5. Increased capacity building
6. Increased capacity for fundraising
7. Good faith gesture among GMPB partners, especially Cincinnati Zoo/Government of Indonesia
8. Increases biological information database with data from new animals
9. Increased awareness among government and NGOs
10. Gets rid of need to inbreed to continue reproductive potential
11. Demonstrate that bilateral TFCA, REDD and DNS funding really contributes to Sumatran rhino conservation
12. Conservation forest ecosystem restoration (new approach in forestry that allows restoration)
13. Implementing the Government of Indonesia's rhino strategy
14. Could release animals back to wild if needed or hold at SRS short- term for breeding
15. Attractive to donors to move animals around
16. May allow rescuing at-risk rhinos from wild

Potential Risks/Disadvantage:

1. Capture or transport loss
2. May not breed
3. Hemosiderosis
4. Possible NGO criticism for capturing new animals
5. If isolated animals are collected and moved to the SRS, it could decrease the incentive for forest protection

d. Move Torgamba as Ambassador Animal

Potential Benefits:	Potential Risks/Disadvantages:
1. Frees up space at SRS 2. Ambassador animal generates more funds for rhino conservation 3. Generating awareness about SRS 4. Reduce financial burden of keeping non-reproductive animal at SRS 5. If moved to internationally, increased awareness about Sumatran rhinos and potential funding/support 6. Increases capacity building **7.** Gesture of international goodwill if moved out of Indonesia	1. Zoos may not want older animal 2. Transport loss 3. Old age 4. Disease issues