Population Viability Analysis for the Sumatran Rhino in Indonesia

16 – 18 February 2015
Taman Safari, Cisarua, West Java, Indonesia

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For the Sumatran Rhino in Indonesia

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Compiled by the Workshop Participants

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A contribution of the IUCN/SSC Conservation Breeding Specialist Group, in collaboration with the International Rhino Foundation, World Wildlife Fund, PHKA, YABI, Taman Safari, the IUCN/SSC Asian Rhino Specialist Group, and workshop participants.

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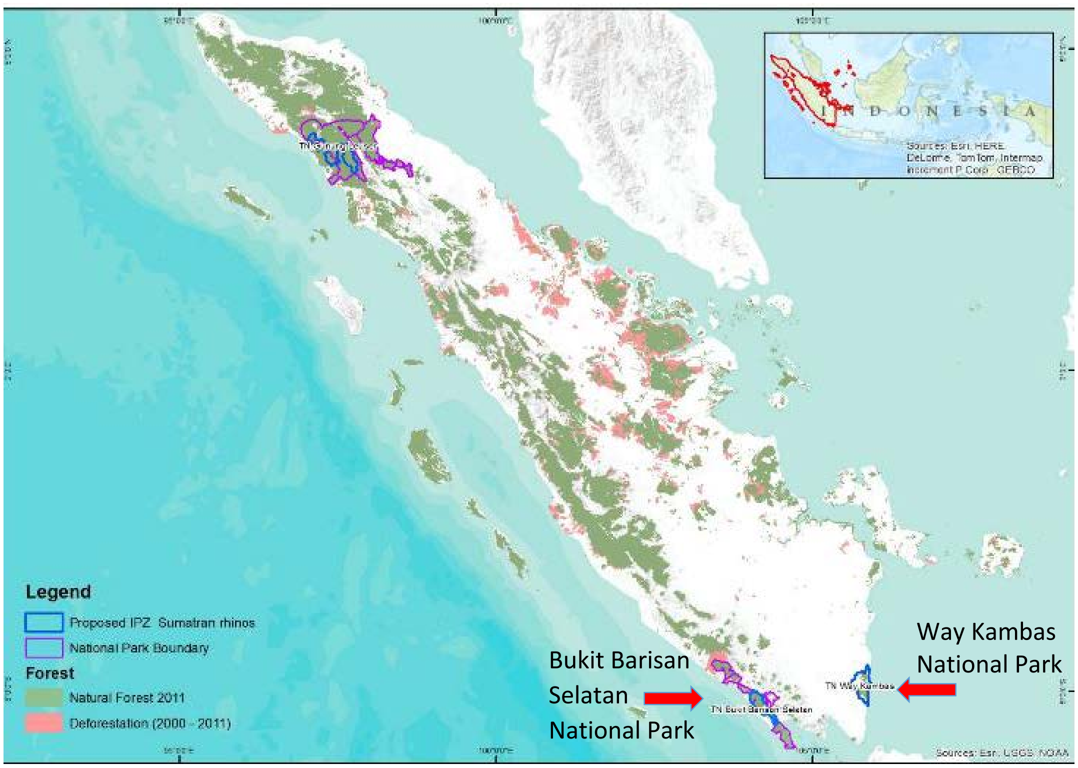
Introduction and Background

The Critically Endangered Sumatran rhinoceros, *Dicerorhinus bicornis*, is the most threatened of the world's five species of rhinoceros. The total population of the Sumatran rhino has declined by at least 70% in the last 25 years; the combination of the extent and rate of population reduction makes it perhaps the most threatened large mammal on the planet.

Experts now estimate that about 100 individuals survive only in Indonesia in Gunung Leuser, Way Kambas, and Bukit Barisan Selatan National Parks on the island of Sumatra (see map below). Within Sumatra, rhinos in these three sites are further divided into 10 smaller subpopulations. Multi-disciplinary surveys of these populations combining patch occupancy, camera trapping and fecal DNA methods are planned for 2016 to verify population estimates. A tiny population also occurs in central Kalimantan, and there is a very slim possibility that a population remains in Myanmar.



Sumatran rhinos once occurred from the foothills of the Himalayas in Bhutan and north-eastern India, through southern China (Yunnan), Myanmar, Thailand, Cambodia, Lao PDR, Viet Nam and the Malay Peninsula, and onto the islands of Sumatra and Borneo in Indonesia (Foose *et al*., 1997). The subspecies *Dicerorhinus sumatrensis lasiotis* formerly occurred in India, Bhutan, Bangladesh, and Myanmar (Nowak, 1999), where it now is extinct.

The subspecies *Dicerorhinus sumatrensis harrissoni* formerly occurred throughout the island of Borneo. Presently, there is no evidence of wild Sumatran rhino populations in Peninsular Malaysia or in that country's state of Sabah. As such, Malaysia recently declared Sumatran rhinos extinct in the wild within its borders (Time, 2015). The subspecies *Dicerorhinus sumatrensis sumatrensis* formerly occurred in Thailand, Peninsular Malaysia, and Sumatra (Indonesia).

The initial decline of the Sumatran rhino was caused by poaching for horn, which is used in traditional Chinese Medicine, and more recently (in Vietnam) as a purported cure for a range of ailments from hangovers to cancer[1], and also as a high value gift item. Now, the species is also threatened by habitat loss and fragmentation, human encroachment and disturbance, as well as catastrophic events such as disease outbreaks, earthquakes, volcanic eruptions, and tsunamis. Additionally, many of these small subpopulations are isolated with no means of genetic exchange. This fragmentation and isolation of subpopulations further increases their risk of extinction because of inbreeding and a failure for males to encounter females often enough and in large enough social groups to produce offspring. Further, without reproduction, females may develop reproductive anomalies that may lead to a loss of reproductive capacity.

Habitat

The species inhabits tropical rainforest and montane moss forest, and occasionally occurs at forest margins and in secondary forest (Nowak, 1999). It occurs mainly in hilly areas nearby water sources, and exhibits seasonal movements, moving uphill in times of lowland flooding (van Strien, 1975). Sumatran rhinos are heavily dependent on salt licks. The species occurs mostly in primary forest in protected areas, but it also wanders into secondary forests outside protected areas, especially in the dry season in search of water (Van Strien, 1975).

Behavior

In the only comprehensive study of the species, van Strien (1986) reported that males are primarily solitary, but can have overlapping territories with females, which are commonly found with offspring (Nowak, 1999). The home range size of females is probably no more than 500 ha, while males wonder over larger areas, with likely limited dispersal distance. The species' life history characteristics are not well known, with longevity estimated at about 35-40 years (Nowak, 1999; International Rhino Foundation website www.rhinos.org, 2015). From captive animals, we know that the gestation length is approximately 495 days (just over 16 months), and age at sexual maturity is 6-7 years for females and 10 years for males (T. Roth, personal communication).

Males are believed to have home ranges of up to 5,000 ha and females 1,000 -1,500 ha (van Strien, 1975). Daily movements between feeding sites and wallows are probably only a few kilometers per day. Longer treks are made when males and females go to saltlicks (5-10 km) and by males exploring their large ranges. Dispersal appears to be mainly by sub-adult animals (4-7 years) old. In this period they may be found rather far from the home grounds. Adults will not move away unless severely disturbed. Water is never very far away in the habitats occupied by the Sumatran rhino (van Strien, 1975).

The Population Viability Analysis Workshop

Fifty-nine people attended the Population Viability Analysis Workshop for the Sumatran Rhino (Appendix II), which was convened by the Government of Indonesia's Ministry of Environment and Forestry in collaboration with its long-time rhino conservation partners Yayasan Badak Indonesia, the International Rhino Foundation, the World Wildlife Fund, and the IUCN-SSC Asian Rhino Specialist Group. The meeting was generously supported by the Disney Conservation Fund and hosted by Taman Safari Indonesia in Cisarua, West Java. Dr. Phil Miller and Caroline Lees from the IUCN-SSC Conservation Breeding Specialist Group facilitated the workshop.

The primary aim of the PVA workshop was to assemble information so that participants could examine factors affecting the Sumatran rhino's survival, to lay out what is known or not known about threats at the various rhino sites, and to consider promising management scenarios. This workshop laid the foundation

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[1] There is no scientific evidence that rhino horn has medicinal value.

for two larger consultative strategic planning exercises, designed to develop a long-range recovery plan for the Sumatran rhino in Indonesia, held in May 2015. These exercises build on momentum from two previous gatherings of rhino experts: the Sumatran Rhino Crisis Summit held in Singapore in April, 2013 and the Asian Rhino Range States Meeting held in Bandar Lampung, Sumatra, Indonesia, in October that same year.

Because of concerns about poaching, detailed information concerning location and numbers of rhinos at the subpopulation level have been omitted from this report.

Future Directions for Conservation Management

Analyses from this workshop indicate that for the foreseeable future the viability of all remaining rhino populations will depend on complete protection from poaching. Even with this in place, populations numbering 15 or fewer are at risk to demographic, environmental and genetic uncertainty and would be expected to benefit from consolidation. For populations of 15-40, ability to persist will be closely tied to the ability to grow, which is expected to hinge on female reproductive performance. Factors affecting this need to be better understood, monitored and managed until consistent growth is secured. Populations of 40 or more Sumatran rhinos are expected to show greater resilience over the time period considered, but only in the absence of human-mediated threats such as poaching. Even with consolidation at the three sites, further expansion in numbers will be needed over time, coupled with low-intensity metapopulation management, to moderate the longer-term issues of genetic deterioration and environmental change.

The problems facing Sumatran rhinos are solvable, but require a level of intensive management and protection not yet in place in Indonesia. Effective conservation action and protection has led to the recovery of two of the five rhino species from fewer than 100 animals since the early 1900s; both the greater one-horned (*Rhinoceros unicornis*) and white rhino (*Ceratotherium simum)* have recovered to more than 3,000 and 20,000 animals respectively. These recoveries have been brought about through strategic consolidation of populations combined with intensive protection and management of core zones in protected areas. These strategies need to be considered, and must be implemented in Indonesia in the very near future if the Sumatran rhino is to survive for the long-term. This document serves as one step in the development of a broad-based recovery strategy for the species.

References

Foose, T. J. and van Strien, N. (eds). (1997) *Asian Rhinos. Status Survey and Conservation Action Plan*. IUCN/SSC Asian Rhino Specialist Group, Gland, Switzerland.

Groves, C. P. and Kur, F. T. (1972) *Dicerorhinus sumatrensis*. *Mammalian Species* 21: 1-6.

International Rhino Foundation (2015) http://rhinos.org/species/sumatran-rhino/

Nowak, R.M. (1999) *Walker's Mammals of the World*, 6th edition. Baltimore and London, The John Hopkins University Press, vol. 2.

Time (2015) Sumatran Rhino Deemed Extinct in Malaysia. http://time.com/4006981/sumatran-rhino-extinct-malaysia/

Van Strien, N.J. (1975) *Dicerorhinus sumatrensis* (Fischer), the Sumatran or two-horned Asiatic rhinoceros: a study of literature. *Netherlands Committee for International. Nature Protection Meded* 22: 1-82.

Van Strien, N. J. (1986) *The Sumatran Rhinoceros Dicerorhinus sumatrensis (Fischer, 1814) in the Gunung Leuser National Park, Sumatra, Indonesia*. Hamburg.

Threats to Sumatran Rhino Viability: An Analysis

Introduction

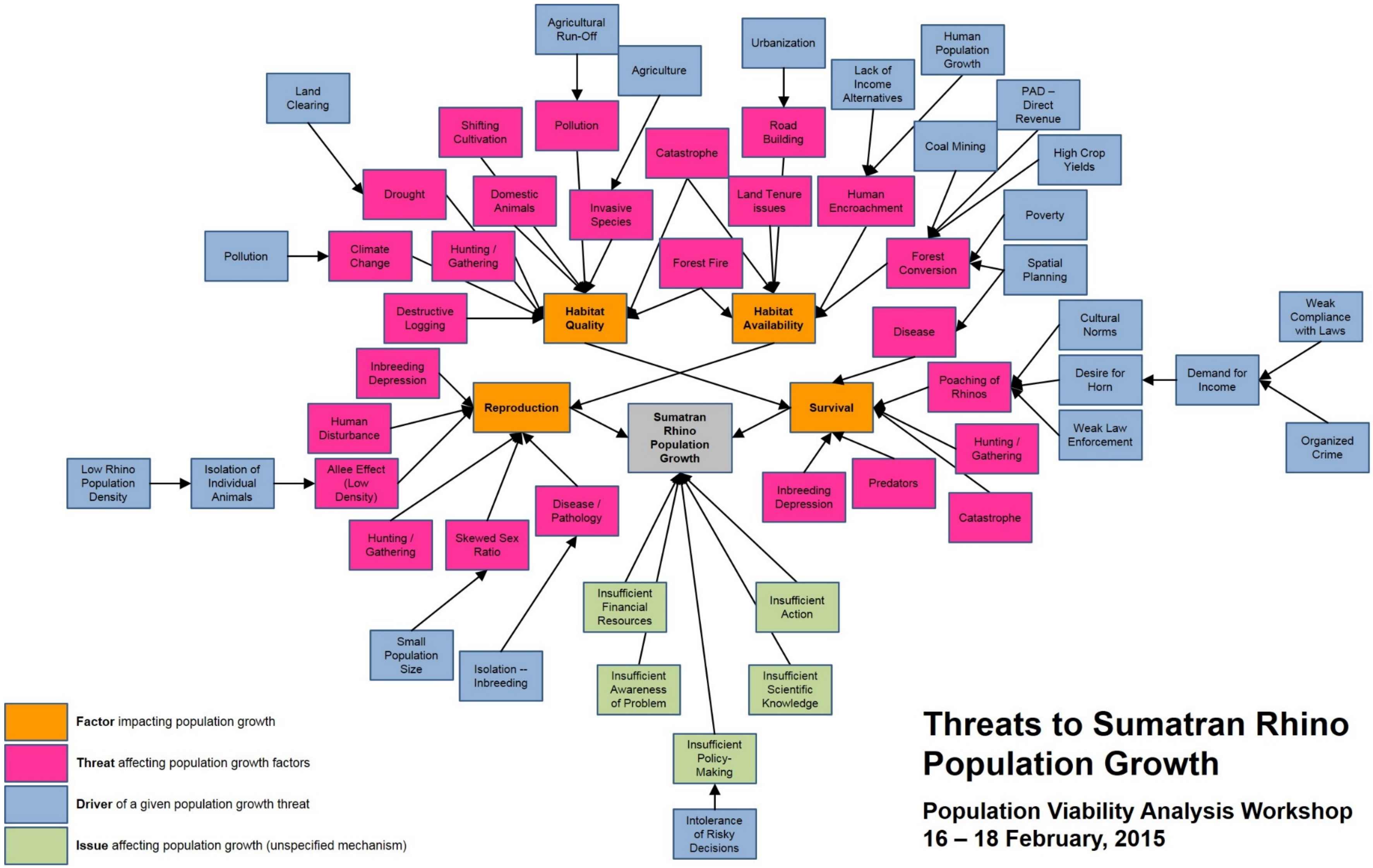
At an early stage in the workshop process, participants built a collaborative “mind map” of the threats to Sumatran rhino population growth and long-term population viability. The identified threats were defined in terms of their impact on one of the primary factors governing population growth in this (and other wildlife) species: reproduction, survival, habitat quality, and habitat availability. Initially, participants were asked to specify the direct threats that directly impact these four factors, to write those threats on an adhesive notecard, and to then attach that notecard to the wall with an arrow linking it to a specific growth factor. Secondly, they were asked to identify one or more indirect threats, also known as drivers, that are linked to one or more direct threats. As an example, rhino poaching can be identified as a direct threat to survival since, by definition, the act of poaching leads to the death of that animal and an overall reduction in the population age-specific survival rate. The primary driver of that poaching threat is the human demand for rhino horn, which is itself driven by the demand for individual or organization income by those engaged in or organizing the poaching activity. By identifying the drivers of any given threat, it becomes easier to develop more effective conservation actions that target those processes. A graphical recreation of the group’s mind map is presented in Figure 1.

Following the creation of this threat map, the workshop participants were divided into four working groups, defined by the geographic region within Indonesia where Sumatran rhinos are known to currently exist: Bukit Barisan Selatan National Park, Gunung Leuser National Park, Way Kambas National Park, and Kalimantan (Indonesian Borneo). The working groups were then asked to more thoroughly analyze the nature and intensity of those threats from the mind map that are currently operating on their particular populations. In particular, the groups were assigned the following four tasks:

- Briefly summarize the status of the population(s) within the region of interest;
- Describe the nature and intensity of the threats operating within the region;
- Prioritize those threats based on their severity and/or geographic scope; and
- Conduct an assessment of the level of knowledge around those threats, among the experts in the working group. In this context, it is particularly important to separate known fact from assumption regarding our understanding of a given threat. Additionally, identification of knowledge gaps is crucial to long-term planning of research and management programs designed to increase our understanding of a given threat.

This information is presented for each geographic region in the remaining pages of this section.

Workshop participants creating the “mind map” of threats to Sumatran rhino population growth and viability during the PVA workshop, February 2015.


Agricultural Run-Off
Agriculture
Urbanization
Lack of Income Alternatives
Human Population Growth
PAD – Direct Revenue
Land Clearing
Shifting Cultivation
Pollution
Road Building
Catastrophe
Coal Mining
High Crop Yields
Drought
Domestic Animals
Invasive Species
Land Tenure issues
Human Encroachment
Poverty
Pollution
Climate Change
Hunting / Gathering
Forest Fire
Forest Conversion
Spatial Planning
Destructive Logging
Habitat Quality
Habitat Availability
Disease
Cultural Norms
Weak Compliance with Laws
Inbreeding Depression
Reproduction
Sumatran Rhino Population Growth
Survival
Poaching of Rhinos
Desire for Horn
Demand for Income
Human Disturbance
Weak Law Enforcement
Hunting / Gathering
Organized Crime
Low Rhino Population Density
Isolation of Individual Animals
Allee Effect (Low Density)
Inbreeding Depression
Predators
Catastrophe
Disease / Pathology
Hunting / Gathering
Skewed Sex Ratio
Insufficient Financial Resources
Insufficient Action
Small Population Size
Isolation -- Inbreeding
Insufficient Awareness of Problem
Insufficient Scientific Knowledge
Insufficient Policy-Making
Intolerance of Risky Decisions
Factor impacting population growth
Threat affecting population growth factors
Driver of a given population growth threat
Issue affecting population growth (unspecified mechanism)
Threats to Sumatran Rhino Population Growth
Population Viability Analysis Workshop
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Bukit Barisan Selatan: Site-specific Characteristics

Population ID: BBS
Current population size: up to 30
Sex-ratio and age-structure: No data
Estimated K: Estimated to have 2,000 km^2 of suitable habitat. Estimated total carrying capacity = 120-200. Carrying capacity only within the Intensive Protection Zone (IPZ) = 60-90
History:

Other details and assumptions (e.g. extent of isolation):

Threat description	IPZ		Tambling		Pattern of occurrence (including trends)?	How does this impact on survival and/or reproduction?
	Rank	**Current or potential?**	**Rank**	**Current or potential?**		
Poaching (S)	High 1=	C	High 3	C	Actively present. All over IPZ.	Removes animals = decrease in survival
Allee effect (R)	High 1=	C	High 1	C	Probably present across the whole population. Possibly increasing. No data and breeding.	Reduces chances of breeding
Human disturbance (natural resource collection activities eg NTFPs, bird collection, fishing etc) (S, R, HQ)	High 1=	C	High 4=	C	Present across the whole population Many paths for people to enter. Increasing.	Rhino moving to avoid people; reduces chances of breeding, stress, less time for feeding, change in habitat so reduction in fitness
Road development (HA)	High 1=	C	-	-	Each edge of the IPZ. Roads to be upgraded so increasing threat.	Reduces K if animals confined to within IPZ. Stress.
Small scale encroachment (HQ, HA)	High 5	C	Low	P	Threat along two edges of the IPZ. Stable.	Reduces K.
Inbreeding depression (S, R)	High 6=	C	High 4=	C	Unknown. More likely to be present in Tambling.	Loss of fitness.
Large scale (adat) encroachment (HA)	High 8	P	-	-	IPZ only; Suoh area.	Reduces K.
Catastrophe (HQ, HA, S)	High	P	High	P	Potentially whole population or any part of it.	Reduces K.

Skewed sex ratio (R)	Medium	P	High 5	P	Likely present in Tambling. Unknown in IPZ.	Reduces effective population size; increases genetic drift; increases inbreeding etc.
Disease (S, R)	Medium	C	Medium	P	Unknown, but likely to effect a % of the population.	Kills x% of population. Reduces fitness.
Invasive species (HQ)	Low	C	High 2	C	Tambling in several places. Increasing threat.	Reduces K.
Reproductive pathology (R)	Low	P	High	P	Unknown. Most likely in Tambling.	Reduces breeding rate.
Forest fire (HQ, HA)	Low	C	Low	C	Usually small and isolated. Frequency may increase with climate change.	Reduces K for some but then may increase K during re-growth. May lead to death of some individuals. May lead to invasive species.

Bukit Barisan Selatan: Information Assembly

Threat 1: *Poaching*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Presence of traps and guns capable of catching rhinos • Shifting of tiger and elephant hunting to rhinos • Many entry points so very hard to enforce • High price of rhino horn • Presence of professional poaching operations in BBS • Middle men in Sumatra asking for rhino horn in Sumbag Sel and Lampung • Middle men never get apprehended • Weak punishment for poachers/traffickers	• Loss of rhinos in Way Bambang and Pemerihan due to no detection of rhino signs • No rhino hunted in BBS since 2002 • Patrolling effort and coverage not sufficient to prevent rhino poaching	• Number of rhinos • Number of rhino deaths; natural or unnatural • Evidence and witnesses to prosecute rhino poachers	• Ngambur north to proposed IPZ has potential for poaching
Threat 2: *Human disturbance (natural resource collection activities eg NTFPs, bird collection, fishing etc)*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• 224 villages around BBS with the proposed IPZ covering 1/3 of BBS • Human presence in all entry points to collect NTFP (gahru, birds etc) • Human disturbance is impacting rhino movement • Market for products • Collectors are never prosecuted as not worth it • 1-6 people per day from one Liwa village (Penyungkaian) entering IPZ • Go to forest when not harvesting or planning coffee	• Low awareness of local community • Local communities need the money derived from NTFP collection for their livelihoods	• How many people entering the park • Market network for illegal products • Community reliance on forest products to develop off-sets	

Threat 3: *Road development*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• 2 national roads flanking the IPZ; Sanggi-Bengkunat (S), Krui-Liwa (N) • Plans exist to upgrade both from 8 to 15 m • No rhinos outside of IPZ area • Decreasing rhino detections close to road in Sanggi-Bengkunat with none since 2010 • People use the roads to enter the forest • 2-3,000 vehicles per day using Sanggi-Bengkunat road • 1,000 vehicles per day using Krui-Liwa road • Rhino crossed Krui-Liwa road in 2010 • Edge effect of 40m and microclimate impact of 60m measured when road was still a dirt track in 1996 • After road paved in 2007 rhino signs decreased	• Poachers use the road • Road has a negative impact on rhinos • Rhinos will not cross roads when heavy traffic (paved road itself does not prevent crossing) • Cannot control human activity along roads • Management of the road and/or green infrastructure could permit rhino crossings	• When and how rhinos can/will cross the road • What speed vehicles need to travel to permit rhino crossing and prevent rhino collisions • Maximum weight and noise level required to minimise impact on rhinos	• No significant road threat outside IPZ
Threat 4: ***Allee effect***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• No rhino calves found in Tambling since 2000 • Breeding signs seen annually in IPZ • Low density of population • Rhinos moving further than expected • 1 photo after 18 months of camera-trapping from 20 cameras	• Allee effect is present in and outside of IPZ	• Sex ratio • Kinship • Breeding rate • Population size • Number of receptive females not breeding • Impact of human disturbance on breeding success	

Threat 5: ***Small scale encroachment***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• 6% deforestation in IPZ • Most IPZ encroachment in Biha and Ngambur • All encroachment is coffee • Reduces K if not removed • Recovering encroachment (re-growth) is used by rhinos	• Encroachers removed, but coffee harvest still occurs as coffee not removed	• Socio-economic background of encroachers	• Not currently an issue outside of IPZ

Threat 6: ***Inbreeding depression***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Less and less rhino signs found outside of IPZ between 2000-2010	• Inbreeding depression could be present in the population	• Sex ratio • Kinship • Breeding rate • Population size • Number of receptive females not breeding	• Higher probability of presence outside of IPZ

Threat 7: ***Large scale encroachment***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Suoh enclave area adjacent to IPZ and indigenous people want to ask to enlarge it	• An ask to enlarge the enclave will be made • If enclave expanded it will result in large scale encroachment • Encroachment will lead to other illegal activities in the IPZ	• Whether ask will be made	• IPZ only

Threat 8: ***Skewed sex ratio***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
	• May be present in the future	• Sex ratio	• More likely present outside IPZ

Threat 9: ***Disease***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Disease seen in Way Kambas • No current evidence of disease presence • Diarrhoea from young rhinos seen in 3 separate occasions	• Disease is a potential threat • No livestock coming into contact with rhinos	• Susceptibility of Sumatran rhinos to various diseases • Prevalence of disease in the wild and domestic animals in and around BBS	
Threat 10: ***Invasive species***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• 7,000 ha of *Meremia peltata* outside IPZ • Rhino do not eat as get diarrhoea if eat • *Meremia peltata* blankets area and prevents rhino food plants growing • No signs of rhinos are found in areas dominated by *Meremia peltata* • Does not naturally dominate an area; dominates after logging or clearing • Previous eradication program did not work	• Good growing conditions outside of IPZ as it does not dominate in other areas	• How to eradicate/control	• Only an issue outside of IPZ
Threat 11: ***Reproductive pathology***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Occurred in Malaysian populations in low populations • Signs of breeding in IPZ	• Occurrence in low density Sumatran populations	• Presence in Sumatran populations • Impact on pathology on ability to reproduce • Ability to detect without animal capture	• Higher probability of occurrence outside of IPZ

Threat 12: *Catastrophe*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Anak Krakatau is active and has the ability to wipe out BBS rhino population • Floods occur in IPZ due to rivers bursting their banks • Earthquakes lead to landslides and falling trees • Earthquake every 30 years in Liwa area	• Impact of floods and earthquakes on rhinos	• Potential magnitude of impact of floods and earthquakes on rhinos	
Threat 13: *Forest fire*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• 1997 occurred	• Frequency will increase with climate change • Rhinos will not be killed fire • Rhinos may move into less protected forest as a result of fire • Re-growth after forest fire is good for rhinos as provides food plants	• How long does the forest take to recover to a state that is useful for rhinos • How to prevent invasive species dominating re-growth areas • Likelihood of increase in forest fire	

Gunung Leuser: Site-specific Characteristics

Population ID: **1**
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS
Sex-ratio and age-structure: No data
Estimated K: 30 (based on 1 individual requiring approx. 10km2), area is 30,000ha
History: Area had a good rhino population according to the 1993 PHVA, but then it became increasingly isolated due to road development in the surrounding area (from mid 90s). Part of the Leuser ecosystem but outside of the National Park. The area is a Protection Forest (Nagan Reya district, central Aceh)
Other details and assumptions (e.g. extent of isolation): road between Beutong and Samarkilang and the two are very far away from each other.

Population ID: **2**
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS
Sex-ratio and age-structure: No data
Estimated K: Site is 90,000ha, 90
History: The most threatened of all populations. Part of Leuser Ecosystem but very far from the national park. In 1990s a reasonably good population was present but since then the area was logged as part of the timber concession, until 2001. Rhinos not detected during occupancy survey for tigers (2009) but detected more recently specifically targeting rhino.
Other details and assumptions (e.g. extent of isolation): road between Beutong and Samarkilang and far away from each other, Samarkilang separated by villages from Kappi. Increasing threat of road development and development of industrial timber concession (monoculture) and encroachment.

Population ID: **3**
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS
Sex-ratio and age-structure: No data
Estimated K: 3
History: Inside the core zone of the national park since it was established in 1981. Previously it was inside a wildlife sanctuary (since 1934) which was proposed by local leaders. The first formal legal document on conservation for Leuser.
Other details and assumptions (e.g. extent of isolation): Habitat is still connected with west Leuser population. Road between Kemiri and Kappi, Mount Leuser between Kemiri and Babah Rot (north area of Leuser Barat). Potential disturbance from hikers (intensive hiking activity)

Population ID: **4**
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS
Sex-ratio and age-structure: No data
Estimated K: Site is, 100,000ha, K estimated at 100
History: Inside the core zone of the national park. Rhino population known since the colonial era.
Other details and assumptions (e.g. extent of isolation): Kappi separated by barriers including mountains and roads, or large distance between populations with no signs in between.

Population ID: **5**
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS
Sex-ratio and age-structure: No data
Estimated K: Site is 1200km2 but only around 10% of the area is thought to be available to rhinos because of the steep terrain. Estimated K is 12
History: Rhinos were detected here only recently during tiger occupancy survey in 2010. Intensive camera-trapping for tigers in 2014 did not record any rhinos. In 2002 camera-trap surveys for tigers (900 camera-trap nights) did not record rhinos.
Other details and assumptions (e.g. extent of isolation): Habitat connectivity between Kappi and Bohorok but mountain between Kappi and Bohorok may prevent movement between the populations. Very high level of human activities (tourism, hunting of other wildlife, NTFP, fishing) near Bohorok. Major road between Bohorok and west Leuser.

Population ID: **6**
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS Around 300 camera trap nights in Menggamat Meukek – no photos of rhino but signs present.
Sex-ratio and age-structure: Evidence of breeding (calves), 4 males and 6 females and 2 calves (female) identified in Mamas by camera-trapping in 2014 (3150 camera-trap nights, 1008 frames).
Estimated K: Size of area 400,000ha, estimated k is 400
History: Part within the national park and part outside (protection forest).
Other details and assumptions (e.g. extent of isolation): - Within West Leuser – the big river between Menggamat Meukek and Babah Rot - barrier to dispersal? Also, there is a big ridge between Mamas and Menggamat Meukek - barrier to dispersal?

Threat description	Priority	Current or potential?	Pattern of occurrence (including trends)?	How does this impact on survival and/or reproduction?
Threats to survival				
Poaching	High	Current	Increasing	
Catastrophe	High	Current	Increasing	
Disease	Low	Potential	Increasing	
Inbreeding depression	Medium	Potential	For very small populations	
Food/nutrition	Low	Potential	Increasing, for Samarkilang and Beutong	
Threats to reproduction				
Inbreeding depression	Medium	Potential	Increasing	
Disease	Medium	Potential		
Sex ratio	Low	Potential	For very small populations	
Catastrophe	High	Potential	?	
Allee effect	Medium	Current	For very small populations	
Naturally low reproductive rate	Low	Potential	?	
Human disturbance	High	Current	Increasing	
Threats to habitat quality:				
Forest fire	Medium	Current	Increasing	
Encroachment	High	Current	Increasing	
Destructive logging	Medium	Current	Increasing	
Human disturbance	High	Current	Increasing	
Catastrophe	Medium	Current	Increasing	
Pollution	Low	Potential	Increasing for very small populations outside the park	
Livestock	Low	Potential	Increasing, Samarkilang and Beutong	
Threats to habitat availability				
Forest Conversion	High	Current	Increasing, Samarkilang and Beutong	
Encroachment	Medium-High	Current	Increasing at all sites	
Road development	High	Both	Increasing at all sites	
Land tenure system	Medium	Current	Increasing in Samarkilang and Beutong	
Catastrophe	Medium	Current	Increasing	
Refugees	Low	Current	Increasing, particularly in Samarkilang and Beutong	
Aceh spatial plan	Medium-High	Current	Increasing, all sites	

Gunung Leuser: Information Assembly

Threat 1: *Poaching*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• There are a lot of snares for large mammals in the forest	• Poaching is a threat to the rhino population in Leuser	• Intensity and distribution of poaching	• NA
• There is an active poacher network in Aceh, North Sumatra and across Sumatra, targeting tigers, hornbills, elephants, deer pangolins		• Poaching network only partially identified	
• Existing illegal trade of wildlife in Sumatra		• Specific trade data on rhino lacking and who is involved in trade needs to be determined	
• Demand for wildlife and rhino horn is present			
Threat 2: *Catastrophe*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Flooding occurs regularly in some areas, with forest fires, landslides, and El niño events (e.g., 1997) occurring as well.	• Not a significant threat but it is believed the distribution of the rhino decreased in SW Aceh and Way Kambas in 1997 following forest fire (El niño). We assume these events affect food availability and may isolate some individuals (increase population fragmentation)	• Don't know the impact of these events on the rhinos	• Particularly SW Aceh

Threat 3: ***Human Disturbance***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Recent increase in human activities (NTFP collection including fishing, sandalwood extraction, poaching, bird collection)	• These activities will continue to increase	• Frequency and the distribution of these activities is not well known, along with the people involved	• Highest frequency outside of the national park
• Rhinos avoid areas with high levels of human activities (studies from Aceh and BBS)	• Assume the research methods are robust and the studies are accurate	• Impacts of specific activities on rhinos not known	
• Illegal and legal mining is occurring in some areas	• These activities are disturbing the rhino populations	• Don't know how long this will continue, or if it will increase/decrease	• (Not included due to security concerns)
Threat 4: ***Human Encroachment***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Encroachment takes place within the national park, protection forest, converting forest into different commodities and plantations (oil palm, cacao)	• Once encroachment has taken it is irreversible and the area will no longer be available for rhinos	• The details including whereabouts and people involved are not well known.	
• Satellite imagery shows decreasing forest cover	• Encroachment will continue to increase		• (Not included due to security concerns)
• Some players are already known in some areas		• In some areas, players are not known	
• Some enforcement has taken place			
• The demand and price for commodities is still very high, driving the encroachment			

Threat 5: ***Forest Conversion / Land Tenure***

Facts	Assumptions	Information gaps	Regional specificity
• There is a new provincial and district level spatial plan that includes the allocation of some forest areas to be converted	• The spatial plan will be implemented • The spatial plan will reduce habitat for the rhino and fragment the habitat even further	• We don't know the specific impacts on the rhino population	• (Not included due to security concerns)
• There is also a plan to develop a hydrodam (proposed)	• The dam inundate some of the rhino habitat and reduce the area available for the rhino	• We don't know the specific impacts on the rhino population	• (Not included due to security concerns)
• One of the permits for industrial timber concession in Samarkilang	• The concession will go ahead and reduce the available habitat for the rhino population	• We don't know the specific impacts on the rhino population	• (Not included due to security concerns)
• Conversion of forest for human settlement	• The available habitat for the rhino populations will be reduced		• (Not included due to security concerns)

Threat 6: ***Road Development***

Facts	Assumptions	Information gaps	Regional specificity
• A road has been built from Kutacane	• The road will be widened and the use of the road will be intensified		• (Not included due to security concerns)
• A second road has been developed from Blangkejeren to Perlak			• (Not included due to security concerns)
• A third road has already been built from Blangkejeren to Blang Pidie and will be improved			• (Not included due to security concerns)
• There is a plan to develop a road from Kutacane to Bohorok	• Road expansion will be implemented – increasing economic activities, growth • Road development will be followed by other human activities, including encroachment, settlement, etc • Smaller tracks leading off these roads can potentially be developed into roads as well	• Information needed for advocacy to prevent road development across forest areas and implement mitigation efforts	• (Not included due to security concerns)
• There is a plan to develop another road from Kutacane to Gelombang			• (Not included due to security concerns)
• Road development plan from Pondok Baru to Samarkilang to north Aceh and Samarkilang to Peuharon			• (Not included due to security concerns)
• Jamat to Lokop			• (Not included due to security concerns)
• Small roads already in SE Aceh			• (Not included due to security concerns)

Threat 7: *Inbreeding / Allee Effect*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Many of the populations are very small	• The population estimate is accurate	• Population number is not clear • Sex ratio is not known	
• Habitat patches/populations are isolated by natural and man-made barriers (roads, mountains, rivers, settlements)	• We assume the barriers prevent rhino movement • We assume surveys have been conducted thoroughly in the areas between the populations	• Data on individual movement and genetic information related to inbreeding potential, genetic diversity, relatedness, etc. is lacking • Unknown whether the barriers actually prevent movement of rhinos between populations • Rhino absence/ presence in between habitat patches/populations	
Threat 8: *Disease*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• There are hunters with dogs using these areas	• Dogs may transmit diseases to the rhino population	• No research has been conducted on the risk of disease transmission to rhinos	• (Not included due to security concerns)
• Livestock are free-ranging in some areas	• Livestock may transmit diseases to the rhino population	• No research has been conducted on the risk of disease transmission to rhinos	• (Not included due to security concerns)
Threat 9: *Destructive Logging*			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Destructive logging is taking place in some areas	• We assume the logging and associated disturbance will disturb the rhinos. • Logging affects the availability of rhino food, wallows and trails	• Impacts of logging on the rhino populations	• (Not included due to security concerns)
• There is still high demand for timber	• The timber is coming from the nearby forest	• The source and destination of the timber is unknown	
• Sawmills are still operating			

Way Kambas: Site-specific Characteristics

Population ID: Way Kambas
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS
Sex-ratio and age-structure: Unknown
Estimated K: Unknown, but it could be increased with rhino food replanting in previously-encroached areas.
History: Way Kambas was a logging concession until the early 1970s, and was declared a game reserve in 1982. People were used to accessing the area through logging trails and roads. WKNP was established in 1986. Rhino signs were detected as early as 1982. In 1987, a group of students from the UK doing an elephant study saw a rhino in Way Kanan. The Sumatran Tiger Project in Way Kambas captured 12 photos of rhinos using camera traps set for tigers in 1995. The RPUs began working in WKNP in 1995. In 1997-1999, the population was estimated to be 24 rhinos.

Other details and assumptions (e.g. extent of isolation):

Threat description	Priority	Current or potential?	Pattern of occurrence (including trends)?	How does this impact on survival and/or reproduction?
Poaching		Current	The last poaching event in WKNP was in 2006. While poaching is not currently occuring in the park, it is an ever-present threat, and serendiptious 'take' of rhino by poachers targeting other animals is possible (as was the case in 2006).	Impact on both survival and reproduction. Wtihout sex-ratio data, and individual identification of animals hard to determine the scope of the impact. But if breeding animals were poached it would significantly affect both reproduction and survival.
Human disturbance, including hunting and gathering		Current	Different in the dry season and the wet season. There is more disturbance in the dry season. Most of the disturbance is in Wako and Way Kanan, and on the border of the park. The pattern of disturbance is increasing; people are using the old logging trails/roads to access the park. In the wet season, these trails are closed due to flooding.	We assume that it affects both survival and reproduction. In the rhino core area, we still are finding snares. Rhinos are not frequenting the areas where the snares are being set. We have a lot of data gaps but we do know that at least 2 calves per year have been detected for the past 2 years.
Drought (catastrophic and annual)		Current	Every year there is at least a 2- month drought in WKNP. There was a catastrophic drought in 1997. The annual droughts now have an unpredictable onset and duration. Water is disappearing faster from the park in the dry season.	Droughts impact survival. It may help reproduction because animals have to congregate at wallows and water sources.

Forest Fire (catastrophic and annual)		Current	In 1997, 70% of WKNP was affected by forest fire. And every year, forest fires occur and appear to be increasing.	Forest fires may indirectly impact survival because it affects habitat quality.
Pesticides		Current	Presence of pesticides is increasing along with increasing intensive farming.	Pesticides are likely to have more effect on survival. The effect on reproduction is unknown, but it is possible that pesticides could have a negative effect (e.g., results such as skin sloughing affecting general health).
Pollution		Current	Presence of pollution is increasing along with increasing plantations and intensive farming.	Pollution is likely to have more effect on survival. The effect on reproduction is unknown, but it is possible that pollution could have a negative effect (e.g., results such as skin sloughing affecting general health).
Human encroachment		Potential	Current level zero. Since 2010, 100% of encroachment in WKNP has been eliminated.	Encroachment may indirectly impact survival because it affects habitat availability and quality.
Disease		Potential	Disease risk is increasing as buffalo are entering the park again after they were removed from the park in 2010. Additionally wild elephants are visiting villages where they could pick up and transmit disease back into the park	Disease would likely affect survival; effects on reproduction are unknown, but it is thought that the effects could be negative.

	Low	Medium	High	Potential	Not Applicable	Comments
Threats to reproduction						
Reproductive pathology					XX	No data to support in WKNP
Skewed sex ratio					XX	No data to support in WKNP
Catastrophe	XX					
Low reproductive rate					XX	Species characteristic, not something that can be managed
Allee effect	XX					Based on distribution maps, animals are clustered in the center of the park and should have no trouble encountering one another
Human disturbance			XX			
Inbreeding depression					XX	No data to support in WKNP
Habitat quality	XX					
Disease	XX			HIGH		Potential threat, at present there is no *Brucellosis* in Lampung province
Threats to habitat quality						
Destructive logging	XX					There is local illegal logging, not logging concessions. Most illegal logging is on the border of the park where it can be considered a medium-level threat.
Climate change	XX					Increased forest fires are occuring along the boundary of the park
Drought			XX			Catastrophe
Shifting cultivation					XX	None in WKNP area
Pollution			XX			Livestock, farm runoff
Pesticides			XX			Coming from villages and fruit plantations at the mouths of the three rivers
Invasive species				MEDIUM		Eucalyptus (*Acacia*) tree
Annual forest fire			XX			Forest fires occur every year in the dry season, but not in the core areas.

	Low	Medium	High	Potential	Not Applicable	Comments
Threats to habitat availability						
Road development					XX	
Human encroachment				HIGH		Encroachers evicted from the park in 2010 but encroachment could recur, depending on WKNP management
Forest conversion					XX	
Oil palm					XX	
Catastrophic forest fire			XX			
Threats to survival						
Disease from domestic animals	XX			HIGH		
Poaching	XX			HIGH		Many hunters now using large snares that could catch rhinos
Hunting and gathering				HIGH		
Human disturbance			XX			
Catastrophic forest fire			XX			
Catastrophic drought			XX			
Predators	XX					

Final ranking of threats (points)

1. Poaching (potential threat) (8)
2. Human disturbance (8)
3. Drought (annual and catastrophic) (5)
4. Forest fire (annual and catastrophic) (5)
5. Pesticides (3)
6. Pollution (1)
7. Human encroachment (0)
8. Disease (potential) (0)
9. Hunting and gathering (0)

Way Kambas: Information Assembly

Threat 1: *Poaching*		
Facts	**Assumptions**	**Information gaps**
• The last WKNP Sumatran rhino poaching incident was in 2006. The carcass was found in the dry season and the animal was trapped in the wallow. Deer hunters found the rhino trapped in the wallow and shot it but it is not clear if they took the horn.	• Deer hunters • Luck, not organized crime targeting WKNP	• Don't know whether the horn was taken or not. • Don't know details about hunters.
• RPUs are finding large snares in the park set for tigers but which could trap rhinos. Four snares were found last week (February 2015) in the southern section of the park. In December, 15 snares were found in a 1-km section of a canal (in the central part of the park; one sun bear was snared and rescued. In 2012-2013, RPUs removed 30 snares from WLNP.	• One poaching gang leader is known to the RPUs (northern section of the park). • There are at least two groups of poachers operating in WKNP. • Local syndicates, possible linkages with crime boss in Palembang who sends products to Singapore or Bali.	• Degree of linkages with international wildlife crime syndicates (e.g., Vietnam, China) • Trade routes for rhino horn coming from Sumatra
• Often illegal fishers are caught with snares in their possession along with their fishing gear (as well as bird traps). Some fishermen have been caught with electrocution equipment used for fishing.	• Illegal fishers with snares could/would trap a rhino if the opportunity arises • Professional poachers disguise themselves as fishermen to enter the park • Illegal fishermen who come to Way Kambas may inform professional poachers about how best to enter the park	• How many illegal fishermen are also bringing snares into the park? • Don't know identity or linkages of informant fishermen with professional poachers
• The coastline of WKNP is essentially unprotected and could be an approach route for poachers (speedboat could allow rapid entry and exit). Poachers are entering the park from at least three locations, including from the northern portion of the park near the coast	• Coastline is an entry point for poachers	• Are poachers entering the park using coastline?
• In 2013, a poaching gang leader was arrested who admitted to setting more than 30 tiger and 5 rhino traps. There was insufficient	• He is no longer operating.	• Whether he is still operating in the park.

evidence to prosecute him successfully. An agreement was made with the head of the village and the poacher that if he is caught again, he will be taken to jail.		
• In 2014, six elephants were killed in WKNP (WCS, RPU and WKNP data). On 2 October 2014, an elephant was shot and tusks and teeth removed in the Wako area – which is a core rhino area.	• Elephant was killed by local people, supporting a larger syndicate. • Elephant areas are known to poachers (Wako, Kuala Kambas, Margahayu)	• Linkages to international or domestic wildlife crime syndicates. • Trade routes for ivory.
Threat 2: *Human disturbance*. Humans entering the park to conduct activities, including illegal (e.g., Illegal fishing, illegal gaharu collection, bird catching, setting decoy fires in dry season to place attention of NP staff away from actual illegal activity), and legal activity such as official workers (uncoordinated camp making and use, track use, camera monitoring, etc.). Not all people know about or follow regulations concerning encounters with rhinos. NOTE: ALSO INCLUDES HUNTING AND GATHERING AS A POTENTIAL THREAT		
Facts	**Assumptions**	**Information gaps**
• There is a great deal of illegal activity in WKNP.	• We know what kind of illegal activity is going on in the park and a good idea of the severity/extent of these activities in many areas of the park. • Current levels of protection are insufficient.	• Information on illegal activity in the park in all areas. • What level of protection is needed to decrease or stop illegal activity?
• Rhinos do not utilize the entire park.	• Human disturbance and resultant things such as fire are keeping the rhinos from using the whole park. • If we stop disturbance, especially resulting fires, we could increase the habitat usage.	• How to increase habitat use
• There are wildlife products in the local markets.	• Wildlife products in the local markets come from the national park. • There is still a high demand for wildlife products.	• What species are sold in the markets and at what levels?
• There is no buffer zone in WKNP so there is easy access by local people to all areas of WKNP. Some village roads are connected to the park. Before the park was established there were many villages inside the park.	• Cultural reasons and habit are behind continued illegal entry into the park. • Loyalties among villagers take precedence over worries about being caught doing illegal activities.	• How can previous research on villagers' perceptions of the park help address the problem?

Threat 3: ***Forest fires***		
Facts	**Assumptions**	**Information gaps**
• There are many forest fires annually set by people engaged in illegal activity in WKNP, mostly poachers.	• There are more fires in the dry season. • If there is a 2-week drought, even in the rainy season, the probability of fire is higher.	• Do fires decrease vegetation significantly and if so, how would it affect rhino areas?
• Forest fires prevent the rhinos from fully utilizing the whole park.	• If we could reduce forest fires, forest cover could increase and rhinos could utilize the entire park.	• What is the most effective way to reduce forest fires? • How much capacity is needed to adequately control fires?
• Firefighting capacity is insufficient in the park, especially in the dry season.	• If capacity was in place, we could control the fires.	• What is the most effective way to reduce forest fires? • How much capacity is needed to adequately control fires?
• So far, fires have not been in the core rhino area.	• If fire were in the rhino area, the animals will move to a safer area.	• Do rhinos actually move to safer areas in the event of a fire?
• In the 1997 catastrophic fire after a long dry season (Indonesia-wide) almost 70% of the park was affected, but large mammals survived. The Wako area and the Way Kanan section (area around the SRS) did not burn.	• Rhinos move to a safer area when fires occur.	• Do rhinos actually move to safer areas in the event of a fire?
• Every 5 years there is a long dry season in which fires increase.	• This cycle will continue as it has in the past.	• Might this cycle change with climate change effects?
• When arrests are made, villagers often set retaliatory fires.	• Villagers and the park don't have a good relationship.	• Why do villagers and the park not have a good relationship? • What could be changed to improve the relationship?

Threat 4: *Drought*		
Facts	**Assumptions**	**Information gaps**
• Every year there is at least a 2- month drought in WKNP.	• This cycle will continue as it has in the past. • The impact of the drought is an increase in temperature year after year.	• Might this cycle change with climate change effects?
• Every 5 years there is a drought (long dry season).	• This cycle will continue as it has in the past.	• Might this cycle change with climate change effects?
• Water resources disappear faster during the drought. Some of the river (source of water) from the river is outside of the park.	• Every year is worse as temperatures increase. • Villages assume that water disappears because of plantation use.	• Actual disappearance rates of water. • Hydrology dynamics. • Does plantation use significantly deplete water supplies?
• The length of the dry season is unpredictable.	• The start and end of the dry season will continue to be unpredictable.	• Might this be affected by climate change?
Threat 5: *Pesticides*		
Facts	**Assumptions**	**Information gaps**
• Pesticides (Klorotelonil and Mankozeb) now found in browse gathered for SRS (2006).	• Pesticides are having a negative effect on wildlife food sources.	• Extent of effect of pesticides.
• Pesticides were found in the blood serum of the SRS rhinos, corresponding with sloughing off of soft tissue around the feet and the horn.	• Negative effect on health of rhino	• Extent of effect of pesticides in the wild area (e.g., runoff, residual effects, half-life) • Long term effects of pesticides on animal health.
• Poison (e.g., Potassium chloride) has been used in fishing in river areas outside of the park. The river then flows into the park which is affected.	• Poison has a negative effect on wildlife food and water sources.	• Extent of effect of poison on water sources.
Threat 6: *Pollution*		
Facts	**Assumptions**	**Information gaps**
• Manure from farms outside of the park is flowing into river and into the park.	• Farm run-off negatively affects non-fish wildlife. • No waste treatment for farm run-off. • BAPPEDALDA is not effectively controlling farm run-off and waste management	• What effects does farm run-off have on non-fish wildlife? • How to coordinate with BAPPEDALDA to change waste management practices
• Fruit plantation (e.g., banana, pineapple, guava) chemical waste and nutrients are flowing into the river and then into the park, leading to massive fish die-offs as a result.	• Fruit plantation chemical waste and nutrients negatively affect non-fish wildlife. • No waste treatment for plantation run-off. • BAPPEDALDA is not effectively controlling plantation run-off and waste management	• What effects does farm run-off have on non-fish wildlife? • How to coordinate with BAPPEDALDA to change waste management practices

Threat 7: Human e*ncroachment (Potential)*		
Facts	**Assumptions**	**Information gaps**
• In 2010, WKNP successfully removed 6,000 ha of encroachment, removed buffalo, and human settlers	• Without good park management, encroachment and its negative effects could come back.	• How to prevent future encroachment
• There are still some illegal fishing settlements in coastal area (Kuala Kambas, Wako, Sekapuk)	• Without good park management, the settlements could become permanent	• How to completely remove settlements and prevent future settlements
Threat 8: *Disease (Potential)*		
Facts	**Assumptions**	**Information gaps**
• Domestic animals, especially buffalo, cattle, sheep, and elephants in the Elephant Sanctuary carry diseases and endoparasites that could negatively affect the health of rhinos.	• Transmitted endoparasites could affect the quality of health and reproduction of rhinos.	• Transmission of viruses unknown.
• Endoparasites are transmitted at grazing sites and village areas between domestic animals and elephants. So far this has not been seen in wild rhinos.	• Elephants or wild pigs could transmit endoparasites to rhinos in the park.	• Quantifiable threat of endoparasite transmission from elephants and wild pigs to rhinos.
• Infectious diseases such as Brucellosis and Anthrax are not present in WKNP.	• Infectious diseases such as Brucellosis and Anthrax are not a threat to rhinos at present.	• What is the future risk of infectious diseases such as Brucellosis and Anthrax to rhinos because of the movement of livestock?

Kalimantan: Site-specific Characteristics

Population ID: Kalimantan
Current population size: OMITTED FROM THIS DOCUMENT FOR SECURITY REASONS
Future island wide survey required.
Sex-ratio and age-structure: Unknown
Estimated K: Zone 1 connected to Murung Raya Forest, total approximate size - 500,000 hectares.
Zone 2: 120,000 hectares
Zone 3: less than 10,000 hectares
Assuming one individual requires 5000 hectares, estimate the carrying capacity of Zone 1 plus Murung Raya is approximately 100 individuals
Assumptions

- Any individuals found in Zone 3 will be moved to Zone 1
- Believe 10,000 hectares in Zone 3 will be converted to industrial timber plantations and mining
- Zone 1 and Zone 2 is fragmented by human settlements and road infrastructure

Threat description	Priority	Current or potential?	Pattern of occurrence (including trends)?	How does this impact on survival and/or reproduction?
Threats to habitat availability				
(a) Forest Conversion Oil Palm Plantations & Rubber plantations Industrial Timber Plantations Mining (including illegal mining) Human encroachment Community Forest Plantations	High	Current	Increasing activity (coal mining/oil palm/logging) Increasing encroachment Community Forest Plantations – Stable but potential for new licenses	Habitat loss/ stress from human disturbance/increased risk of hunting
(b) Infrastructure Development Road and Railway construction Human settlements Mining infrastructure	Medium	Current	Increased development activity driven by the district in Zone 1 (current) Trend to increase in the near future. Zone 2 and Zone 3 stagnant	Habitat fragmentation/ increased rhino isolation/ increased risk of traffic accidents
(c) **Forest Fire** Forest clearing for non-forest uses (cause: plantations and shifting cultivation) Poaching Long dry season/lightning strikes Bad habitats by local communities	Medium	Potential	In zone 2 and zone 3	Habitat loss/ reduced habitat quality/ increased risk of mortality
(d) **Catastrophes** Flooding/landslides	Low	Potential	All zones	Temporary loss of habitat & fragmentation
(e) **Land Tenure Issues** (land claiming by local communities)	Medium	Current	Increasing trend in all three zones	Habitat insecurity. Future potential habitat loss.
Threats to habitat quality				
(a) **Shifting cultivation** (Culture of subsistence farming)	Medium	Current	Zone 1 and 2 increase Zone 3 Stable	Potential habitat loss and increased risk of hunting
(b) **Pollution** (illegal gold mining using mercury and other chemicals,	Medium	Current	Zone 3 – higher threat because of palm oil plantations and mining – local communities	Reduced habitat quality and increased risk of mortality

herbicides and agriculture runoff from palm oil plantations)			cannot use the rivers due to reduced and polluted water quality Zone 1 – lower threat	
(c) Destructive Logging	High	Current	Zone 1 – increasing Zone 3 – stable Zone 2 – declining because there is no active logging	Habitat degradation/ increased risk of hunting& poaching
Threats to reproduction				
(a) **Inbreeding depression** (lack of evidence)	High	Potential	Unknown	Increased risk of reproductive problems
(b) **Human disturbance** due to non-forest timber product (NTFP) collection by local community	High	Current	Increasing in all zones because forest resources decline.	Increased risk of hunting and poaching
(c) **Allee effect** (isolated populations)	Low	Potential	Unknown	Increased risk of reproductive problems
Threats to survival				
(a) **Rhino Poaching**	High	Current	Increasing globally	Declining population leading to possible extinction
(b) **Hunting and gathering** by local communities	High	Current	Stable but depends on local/regional demand	Declining population leading to possible extinction
(a) **Insufficient conservation management** by government	High	Current	Across Kalimantan	Habitat loss and fragmentation. Increased risk of hunting and poaching. Declining population leading to possible extinction

Kalimantan: Information Assembly

Threat 1 (High): ***Forest Conversion***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Time series data –1990, 2000, 2010, 2013 on land cover changes. • Forest conversion has increased (exact figures are available – to be added later). • Mining/Oil Palm and Rubber Plantations are the three main causes of forest conversion. • Unclear land ownership over rhino habitats	• Local communities will continue to encroach on rhino habitat – converting forest to oil palm plantations or for other economic purposes. • District Spatial Plan has identified future area for development so forest conversion will increase. • New permits are being issued to palm oil plantations but are not yet operational. • Lack of political will to protect forest areas and prevent further conversion.	• Land ownership transfer is not monitored. • Lack of information on Industrial Palm Oil Plantations and mining licence transfers • Difficult to find information from the government on permits • No land ownership documentation within the three zones. • Lack of information on management authority covering rhino habitats	Zone 2 and Zone 3 (In zone 1 there are already a number of mining licenses issued. Extraction has not yet started)
Threat 2 (High): ***Unsustainable Forest Management Practices (destructive logging)***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Time series data on forest degradation at district level. • 90% of degradation in the region is caused by logging. • Lack of control and supervision from authorities on forest management practices in logging concessions • Lack of law enforcement (no forest rangers within the district) • Limited uptake of sustainable forest management practices (particularly FSC) in logging concessions. • Only 4 logging companies within Zone 3 are FSC certified	• Lack of skills within forest concessions for sustainable management practices and monitoring biodiversity • Lack of capacity and manpower for law enforcement • Profit is going to the timber industry rather than the logging companies	• Lack of information on supervision mechanisms • Lack of information on logging practices • Lack of information on logging company profiles (subsidiary/holding company ownership and management) • Lack of information relating to biological data within Forest Management Units.	• Unsustainable forest management practices happen in all three zones. • FSC certified logging companies only exists in zone 3

Threat 3 (High): ***Poaching***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Communities are indigenous hunters. Poaching is the main source of protein. • Market demand driven for specific products by local restaurants, pet trade etc. • Evidence of poaching (snares, camps) have been found in all three zones • Limited law enforcement • Shifting cultures in local communities	• Increased threat of poaching • Greater awareness that rhinos exist in Kalimantan • Lack of capacity and manpower for law enforcement • Communities are open to more intensive poaching due to changes in cultural values	• Lack of market information at local/national level on the demand for rhino parts in Kalimantan and internationally. • Lack of information on the wildlife trade network • Lack of information on motives for rhino poaching • Community attitudes to rhino conservation are unknown.	All zones
Threat 4 (High): ***Human disturbance – collection of non-timber forest products (NTFP)***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Communities are indigenous gatherers from forest resources in some specific tribes • Market demand for specific forest products such as agarwood, swallow nests, honey, rattan, gum, tree sap, medicinal plants, • Lack of supervision of NTFP utilisation • Unclear regulation of non-timber product utilisation.	• Communities rely on local natural resources to generate income • Limited land suitable for agriculture cultivation • Increased market demand for NTFP • Communities are becoming more materialistic. Growth in consumerism.	• Lack of information on market demand for NTFP • Don't know what percentage of the local people create the disturbances • Lack of information on the carrying capacity of the forests for NTFP • Lack of data on social/economic status of local communities • Lack of information on market linkages between NTPF producers and buyers	All zones
Threat 5: ***Small population processes***			
Facts	**Assumptions**	**Information gaps**	**Regional specificity**
• Low and fragmented population within the three zones • Limited evidence of breeding	• Inbreeding and Allee effect	• More detailed genetic surveys are required in all three zones (camera traps/DNA/ occupancy)	All zones

Population Viability Simulation Modeling for the Sumatran Rhino in Indonesia

Caroline Lees, Conservation Breeding Specialist Group (SSC-IUCN)

Executive Summary

- Sumatran rhinos occur at four wild sites: Bukit Barisan Selatan, Gunung Leuser, Way Kambas and Kalimantan. Within these sites there may be up to 179 wild rhinos remaining, but that is the high end of an estimate. It is not certain from the information available whether growth is occurring in any of these sub-populations. In addition, there are nine individuals at the Way Kambas captive facility.
- The viability and recovery potential of these remnant populations was explored using simulation models at the 2015 PVA Workshop for Sumatran rhinos, held at Taman Safari, 16-18 February. The results are summarised below. The window considered was 100 years and an extinction probability of less than 5% (or 1 in 20) was used as to distinguish acceptable outcomes.
- Models indicate that the persistence of remaining rhino sub-populations will be determined by a combination of:
    - **Current size**: small sub-populations are inherently at risk of extinction from chance demographic, genetic and environmental effects.
    - **Presence of human-mediated threats**: poaching, livestock-transmitted disease, loss of habitat or of habitat quality through human encroachment and disturbance, could all exert downward pressure on populations of the sizes modelled, increasing extinction risk.
    - **Ability to grow**: without growth, sub-populations will remain vulnerable. Low rhino densities, inbreeding, disease and forest disturbance provide are potential mechanisms through which breeding rates could be reduced and growth inhibited.
- **Female reproductive output** was the single most important contributor to growth in modelled populations. For the mortality rates modelled, female breeding rates of **1 calf every 3-4** years would be required to secure growth.
- **Small population threats**: combined impacts of chance and year-to-year environmental variation in birth and death rates, skews in sex-ratio or age-structure and inbreeding depression caused high rates of extinction in growing populations beginning with fewer than **15** rhinos and in non-growing populations beginning with fewer than **40** rhinos; **EVEN IN THE ABSENCE OF POACHING AND OTHER HUMAN-MEDIATED THREATS**
- **Consolidation** of remaining rhinos sub-populations would be expected to reduce immediately the risks to demographic and environmental uncertainty, slow the rate of inbreeding accumulation and alleviate the impacts of isolation and disturbance on female reproductive capacity. Consolidation at three sites (N=32 at BBS, N=41 at WK and N=50 at GL) and at two hypothetical sites each with N=64 were modelled. In the absence of poaching and disease, 3 and 2-site meta-population models returned low extinction risk (0.4% and 0.0% respectively).
- The inclusion of **poaching** at any level, in any of the scenarios modelled, returned extinction risks in excess of 5%. A poaching rate of 0-4 rhinos per year in populations of 10 – 90 rhinos produced extinction risks of 100 - 24% respectively, over the 100 year period. In metapopulations of 123-128 rhinos consolidated into two and three sites, poaching rates of 0-2 rhinos every 2 years still returned extinction risks of 12.9% (2 sites) and 47% (3 sites).
- With close management the **captive population** could be expected to deliver higher breeding rates, lower rates of inbreeding accumulation and greater resilience to disease than wild populations of the same size. Despite this, the 100-year extinction risk for modelled captive

populations did not drop below 10% for any of the carrying capacities modelled (K=10 - 50) due to the starting size (N=9) age-structure and inter-relatedness of the current population. The addition of two adult rhinos (one male and one female) every 10 years reduced these pressures, lowering extinction risks from 51% to 8% for scenarios with K=10, and to zero where K was at least 30. Depending on its size and performance a reliably breeding captive population could provide a surplus of rhinos for release to wild sites. The allowable harvest for a captive population of N=10 was 0.22 rhinos per year (roughly 1 rhino every 5 years) rising to 0.63 per year for a population of N=30 and to 1.03 rhinos per year for a population of N=50.

In summary, for the foreseeable future the viability of all remaining rhino populations will depend on complete protection from poaching. Even with this in place, populations numbering 15 or fewer are at risk to demographic, environmental and genetic uncertainty and would be expected to benefit from consolidation. For populations of 15-40, ability to persist will be closely tied to the ability to grow, which is expected to hinge on female reproductive performance. Factors affecting this need to be better understood, monitored and managed until consistent growth is secured. Populations of 40 or more are expected to show greater resilience over the time period considered, but only in the absence of human-mediated threats. Even with consolidation at the three sites, further expansion in numbers will be needed over time, coupled with low-intensity metapopulation management, to moderate the longer-term issues of genetic deterioration and environmental change.

Note that these results and implications are based on population models which were built using the best information available at the time of the workshop. There remain many areas of parameter uncertainty. The thresholds and figures reported here should be used as a guide and revised as new information becomes available.

Introduction

Little is known about the biology of Sumatran rhinos, about the numbers and reproductive capacity of remaining populations and about the carrying capacity, long-term safety and quality of currently occupied sites. To prevent further decline of the species management decisions need to be made urgently and in the context of this uncertainty. Computer simulation models, though not expected to be an accurate depiction of wild rhino populations, can inform decisions by: identifying key aspects of life history; clarifying the relative impact of different threats; and comparing the likely performance of alternative management strategies. Analyses of this type are generally referred to as Population Viability Analyses (PVA).

To support discussions at the February 2015 Sumatran Rhino PHVA workshop, held at Taman Safari, Indonesia, PVA models were built using the *VORTEX* simulation program (Version 10.0.7.9) (Lacy & Pollack, 2014). VORTEX models are particularly well-suited to exploring questions about populations numbering a few hundred or less as they incorporate those aspects of demographic, environmental and genetic uncertainty that are known to pose risks to populations of this size. Further details about *VORTEX* are provided in Appendix 1.

The following pages present details about the models constructed, the rationale behind the scenarios explored and summaries of the major findings.

Baseline Models

As so few species-specific data were available to inform the development of models for Sumatran rhinos, baseline model parameters were based on:

- limited data from previous population viability analyses (Soemarna et al., 1994; Ellis et al, 2011; Putnam, unpubl.);
- real data on other rhino species, mainly from captive populations of Asian one-horned rhinoceros, *Rhinoceros unicornis*;
- estimates from experts elicited during the Sumatran Rhino Crisis Summit (held at Singapore Zoo in 2013) and Javan and Sumatran rhino workshops held at Taman Safari, Indonesia, in 2015.

Further information about parameters is provided in Appendix 1.

The following three baseline models were constructed:

1) **Growing Baseline:** a population which grows at 2-3% each year.
2) **Zero Growth Baseline:** a population in which, on average, the number of births is balanced by the number of deaths and the population fluctuates around a constant size.
3) **Captive Baseline:** a population able to grow at 2-3% each year but with reduced susceptibility to inbreeding (as expected in captive populations) and beginning with the same age-structure, sex-ratio and pedigree as the current captive population.

Note that the models include probability-driven annual fluctuations in breeding success, mortality rates and sex-ratio associated with environmental variation and sampling error. However, all baseline models are optimistic with respect to several other factors as they assume:

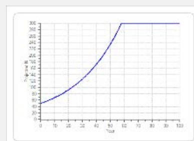
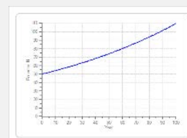
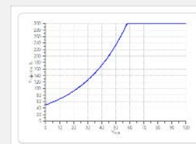
- 100% protection from poaching and habitat encroachment
- No significant disease outbreaks
- No extreme environmental perturbation
- No density-related disadvantages (i.e. they assume animals are able to locate each other and that reproductive rates are not depressed by over-crowding).

THE INCLUSION IN THE MODELS OF ANY OR ALL OF THESE WOULD BE EXPECTED TO DEPRESS RESULTS.

Deterministic characteristics

In the absence of probabilistic effects (stochastic fluctuations in demographic rates and environmental impacts; inbreeding depression; limitations on mates) the baseline models grow at 0.8 – 3.1% each year (see Table 1). Generation time (average age at breeding) is approximately 19 years.

Table 1. Deterministic growth in the three baseline models.

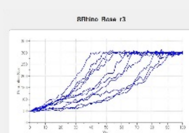
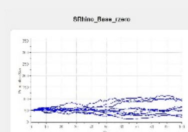
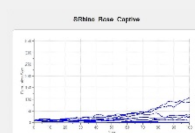
Growth Measure	Growing Model	Zero Growth Model	Captive Model
			
r (instantaneous growth rate)	0.031	0.008	0.031
λ (lambda – annual growth rate)	1.031	1.008	1.031
Ro (growth per generation)	1.690	1.138	1.690
T (generation time in years)	18.85	18.24	18.85

Note that the Zero Growth model has a positive underlying deterministic growth rate.

Stochastic characteristics

The inclusion of probabilistic effects (stochastic fluctuations in demographic rates and environmental impacts; inbreeding depression; limitations on mates) changes the mean rate of growth in all three baseline models (see Table 2.)

Table 2. Impact of probabilistic factors on performance in the three baseline models.

Measure	Growing Model	Zero Growth Model	Captive Model
			
r (instantaneous growth rate)	0.026	0.000	0.008
Standard Deviation in r	0.035	0.049	0.090
Mean size of surviving populations @ 100 years	295.20	64.66	54.94
Probability Extinct @ 100 years	0.000	0.015	0.314
Mean Time to Extinction (MTE)	Zero	85 years	48 years

As illustrated, the inclusion of probabilistic effects exerts considerable influence on the performance of the baseline models. Whilst the Growing Model continues to perform well on average, with a zero likelihood of extinction over the 100 year period, the potential variation in growth trajectory is large (as illustrated by the graph embedded in Table 2). For the Zero Growth baseline, growth shifts from approximately 0.8% per year in the deterministic model to 0.00% per year on average. Fifteen out of 1000 iterations declined to extinction over the 100 year period considered, with a mean time to extinction of 85 years. The Captive baseline, which begins with only 9 individuals (compared to starting population sizes of N=50 for the other two baselines), shows an extinction risk of 31.4% with a mean time to extinction of 48 years. Those captive populations that survived carried a mean population size of N=54.94 at the end of the period.

Sensitivity Testing

[Extract from modelling report prepared for the 2013 Sumatran Rhino Summit, Singapore]

With so few species-specific data there remains much uncertainty around the values used in the models. Some model parameters are more influential than others in shaping population performance and understanding which these are can help us to determine priorities for future action, for research and for monitoring. VORTEX can help by providing a simple and quick way to test the sensitivity of the baseline models to uncertainty in each individual parameter.

Table 3. Results of sensitivity tests: change in annual percentage growth (resulting from varying each individual parameter in turn across a plausible range)

BIG CHANGE (>1%)	MEDIUM CHANGE (0.5-1.0%)	SMALL CHANGE (0-0.5%)
Female inter-birth interval 3, 4, 5, 6 years	**Female age at first/last breeding (years)** • First – 6, 8 • Last – 32, 36, 40	**Density dependence** (Low density inter-birth interval=4 years; High density inter-birth interval=6 years; Effect occurs approaching near and almost at, capacity (B=4, 8, 16))
	Male bias in birth sex-ratio • 50:50 • 55:45	**Coupling good years for birth with good years for survival** YES/NO
	Starting age-structure (N=60) • Young - all 0-20yrs • Medium - all 10-20yrs • Ageing - all 20-40yrs	**Variance in breeding and survival rates** • 20, 30, 40% of mean values
	Age-specific mortality • High juvenile – 25% year 1, 5% after • Baseline – 15% year 1, 5% after • High Adult – 20% years 30-40	**Male age at first/last breeding (years)** First – 10, 12, 14
	Inbreeding 3.14, 6.00, 9.00LEs	**Percent of males in breeding pool** • 60, 80, 100%

One parameter at a time was selected in the baseline Growing Model (e.g. age at first breeding, inter-birth interval, sex-ratio etc.) and was varied across a plausible range of values, keeping all other parameters constant. The size of the impact of this variation on key performance indicators was recorded and compared to that recorded for other parameters. The results are summarised in Table 3, which categorises parameters according to their impact on annual percentage growth.

Female inter-birth interval was the single largest predictor of population performance for the scenarios considered. Also of importance were other factors that operate on female reproductive output (female age at first and last breeding, starting age-structure, changes in mortality rates); on the proportion of females in the population (sex-ratio bias); and inbreeding depression, which in the model acts on juvenile survivorship. Parameters showing only a small impact on population projections were: those relating to male contributions to population performance (percentage of males in the breeding pool, length of reproductive life); the amount of year to year variation in average mortality and reproductive rates; and density-dependent factors. The range considered for the latter may have been too conservative and would benefit from further review.

Generic Models

There is much uncertainty surrounding the number of individual sites at which Sumatran rhinos still occur, how many might occur there, the ages and sexes of remaining animals, whether or not the population is growing, the degree of isolation from neighbouring populations, the quality of habitat in those areas, what threatening processes may be operating at those sites and at what level of severity. A series of generic models were built to explore the potential impact of these factors on extinction risk over time, for populations of different sizes.

Population size

Participants agreed that Sumatran rhinos are currently distributed across a number of potentially isolated sub-populations. Though exact numbers are not known, lower estimates for these remnants range from fewer than five individuals in the smallest fragments, to around fifty in the largest. For a given starting size, growing populations are expected to retain more gene diversity and show lower risk of extinction than those that are not able to grow. It has not been established whether or not remaining fragments are growing and it is possible that some combination of poaching, habitat disturbance and isolation is keeping growth at or close to zero in at least some areas. Therefore, two types of scenario were used to explore the potential impact of population size on viability:

- Zero growth scenarios: in which populations experience zero annual growth, on average.
- Growth scenarios: in which populations experience, on average, 2-3% annual growth.

As in the baselines, zero growth was achieved by manipulating reproduction and survival rates to those required to keep stochastic growth to approximately zero. Population size of 5 - 50 were investigated and the results are shown below.

Populations that are not growing

For "static" or non-growing populations, likelihood of extinction over the 100 year period ranged from 97.2% for n=5 to 1.8% for N=50. Average (mean) time to extinction was relatively short for smaller populations (36 years for N=5) and longer for larger ones (76 years for N=50).

As expected, the larger the population, the greater the likelihood of persistence and the longer the time to extinction. Likelihood of survival did not reach 100% for any of the scenarios explored; populations of 40 or more showed > 95% likelihood of survival; for populations of 15 or fewer the likelihood was less than 50% (see Figures 1a & b).

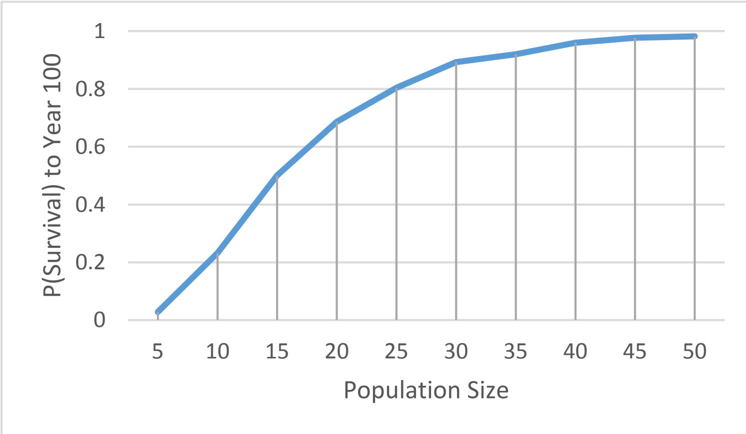


Figure 1a. Relationship between population size and likelihood of survival to 100 years, for populations of various sizes at zero growth.

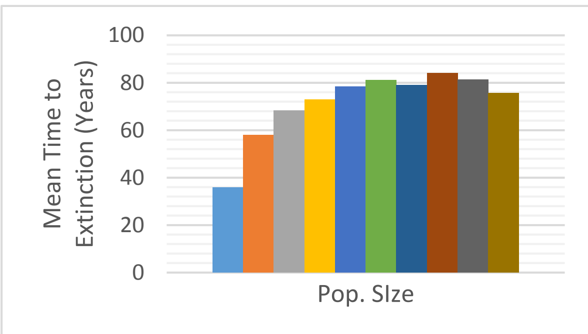


Figure 1b. Average (mean) time to extinction for the same populations. N = 5 shown on the far left bar, N=50 shown on the far right bar, increments of 5 in between.

Growing populations

Populations that begin small but are able to grow show a lower risk of extinction than those whose growth is constrained. Likelihood of extinction for growing populations ranged from 68.0 – 0.0%, whereas the equivalent range for "static" populations was 97.2 – 10.7%. Even in growing populations, extinction risk was high (>5%) for populations numbering 15 individuals or fewer and in growing and non-growing populations of N=5 mean time to extinction was particularly short (36 and 46 years respectively). See Figure 2.

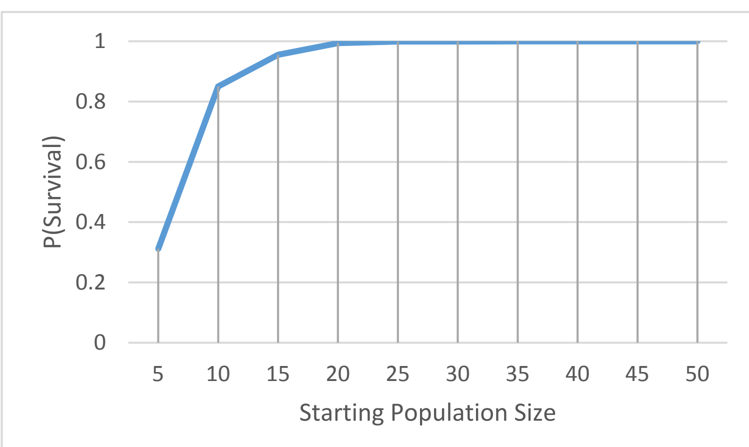


Figure 2. Relationship between population size and likelihood of survival to 100 years, for populations of various sizes growing at 2-3% per year.

Populations that begin small but are able to grow show a lower risk of extinction than those whose growth is constrained. Likelihood of extinction for growing populations ranged from 68.0 – 0.0%, whereas the equivalent range for "static" populations was 97.2 – 10.7%. Even in growing populations, extinction risk was high (>5%) for populations numbering 15 individuals or fewer and in growing and non-growing populations of N=5 mean time to extinction was particularly short (36 and 46 years respectively).

Note that in all of these scenarios populations are at risk to inbreeding, demographic stochasticity and year-to-year environmental variation. In none of these scenarios are they at risk to other threats such as disease, poaching, reproductive incapacity or environmental catastrophes.

Disease

Disease is included indirectly in the baseline model as it would be expected to be a component of annual mortality. However, disease outbreaks can cause a spike in mortality that would fall outside the normal year-to-year pattern of variation in rates. Several diseases carried by livestock are transmissible to rhinos and could cause an outbreak, though no data were available to assist evaluation of the potential frequency or severity of such an event.

The following hypothetical scenario was constructed for illustration: inclusion of a disease event which, in the year it occurs, kills 10% of the population and reduces female reproductive rates by 5%. The frequency of occurrence of this disease was varied from roughly twice to five times to ten times every 100 years. All scenarios were applied to a population numbering 50 individuals at an average growth rate of zero. The results are illustrated in Figure 3 below.

The introduction of disease to the models reduces average population size, decreases growth and increases the likelihood of extinction over the period considered. The more frequent the occurrence, the greater the impact. Likelihood of extinction at 100 years exceeds 5% when the rate of disease occurrence is increased to approximately once every 10 years. Results suggest that a population of this size could withstand occasional disease outbreaks in isolation, but that their occurrence would increase the vulnerability of the population to other threats.

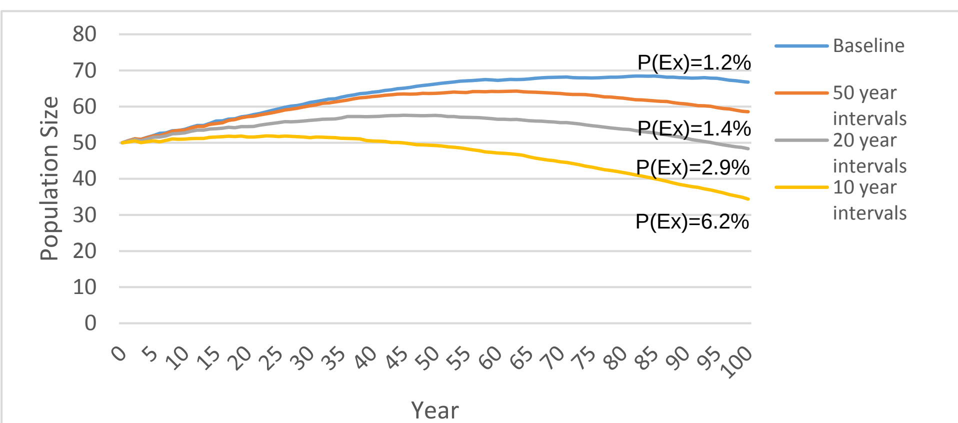
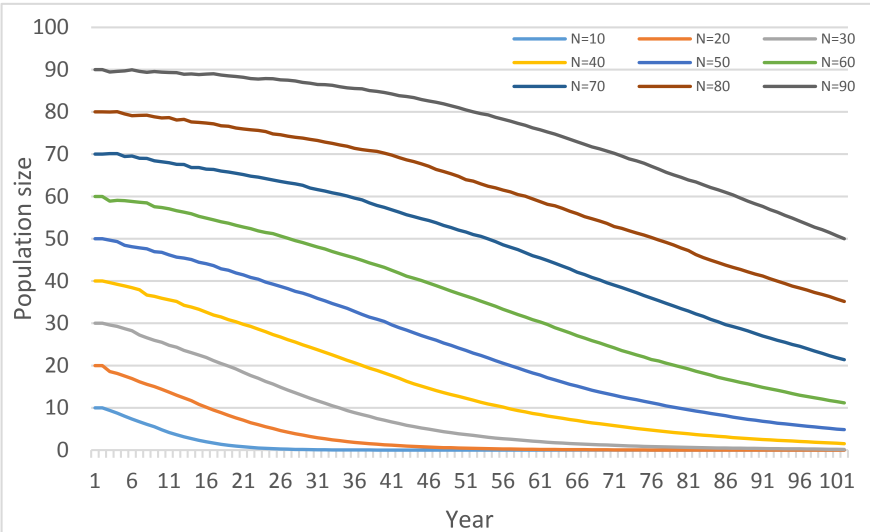


Figure 3. Impact of hypothetical disease on population performance. Likelihood of extinction at 100 years is shown.

Poaching

Poaching was considered to be a potential risk at all sites. Information from other species indicates that poaching should it occur, would be likely to vary in impact from year.

A series of zero growth models was used to explore the potential impact of poaching. Starting population sizes of 10 – 90 were considered, spanning the range of population size estimates for sub-populations at the four remaining sites (Kalimantan, Way Kambas, Gunung Leuser and Bukit Barisan Selatan). The number of animals poached each year was sampled from a normal distribution with a mean of 2 and a standard deviation of 1, such that in most years the number of animals sampled ranged from 0-4 (see Figure 4 for a sample from one model iteration).



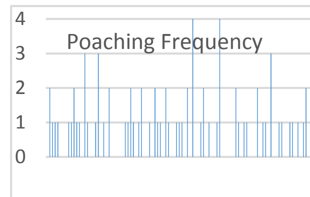


Figure 4. Expected performance of different sized populations with poaching at 0-4 rhinos per year (left); risk of extinction (below); example of year-to-year variation in poaching intensity (above).

Starting pop. size	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
P(Extinct)@100yrs	1	1	0.987	0.938	0.851	0.711	0.519	0.366	0.241
Mean time to extinction (yrs)	12	24	38	51	62	69	74	77	81

As illustrated in Figure 4 population declines and high rates of extinction (24 – 100%) were seen for all population sizes considered at this poaching intensity. Average time to extinction ranged from 12 years for starting population sizes of 10 individuals, to 81 years for starting sizes of 90.

Inbreeding

Matings between close relatives are known to produce offspring which, on average, show depressed fitness. At the individual level this may take the form of increased mortality or reduced capacity for reproduction, and at the population level of an increased frequency of expression of rare genetic disorders (see Frankham et al., 2002).

Where populations remain small and isolated for long periods of time inbreeding will inevitably accumulate. Sumatran rhino populations are thought to have declined relatively rapidly to their current size and degree of fragmentation and, therefore, are expected to carry a relative low level of inbreeding accumulation at this time. This would be expected to increase if no remedial action is taken. Figure 5 indicates the expected pattern of inbreeding accumulation for isolated sub-populations of different sizes over time. As expected, inbreeding accumulates faster in smaller remnants.

Inbreeding is not a threshold effect and the nature and severity of its impact can differ between species, between populations of the same species and for the same population under different circumstances; for example its impact is expected to be more severe in more stressful environments (e.g. O'Grady et al., 2006). As a precaution, many captive programs aim to keep inbreeding accumulation below F=0.125; this is the inbreeding coefficient expected in the offspring of a pairing between half-siblings.

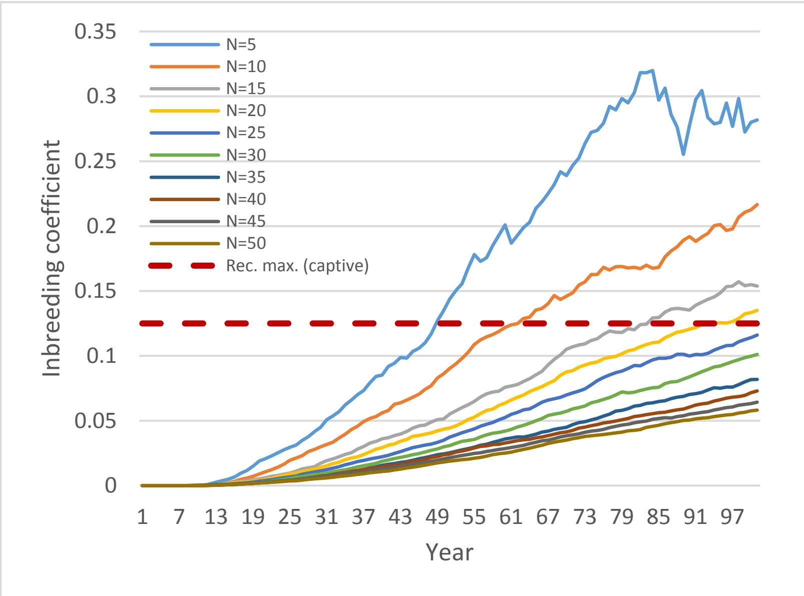


Figure 5. Expected inbreeding accumulation in different sized populations over time. Many captive programs operate to a maximum allowable threshold of F=0.125 (dotted line).

As illustrated in Figure 5, this level of inbreeding would be expected to be reached in 50-60 years (3-4 generations), for populations of 10 individuals or fewer, and in 80-90 years for populations of 15-20 individuals. This threshold is not reached during the 100 year period considered, for populations numbering 25 individuals or more, **assuming that founding individuals are not close relatives**.

Inbreeding affects growth in the models by increasing juvenile mortality, which in turn affects extinction risk. Table 4 compares extinction risk for population fragments of different sizes: with and without inbreeding; and with average growth rates of either zero or 2-3%.

Table 4: Impact of inbreeding on extinction risk for growing and static populations beginning at different populations sizes. Scenarios in which risk of extinction exceeds 5% are highlighted in RED.

	Likelihood population is extinct at 100 years			
	Growing populations		*Static populations*	
Starting pop. size	Inbreeding OFF	Inbreeding ON	Inbreeding OFF	Inbreeding ON
5	0.316	0.688	0.749	0.972
10	0.038	0.150	0.384	0.768
15	0.009	0.045	0.227	0.499
20	0.001	0.006	0.136	0.313
30	0.000	0.001	0.042	0.107
40	0.000	0.000	0.013	0.040
50	0.000	0.000	0.007	0.018

The removal of inbreeding from the models reduced extinction risk in both the static populations and those that were growing, indicating that conservation objectives would be progressed through management interventions that mitigate inbreeding accumulation.

However, treating inbreeding in isolation from other threats – for example by exchanging animals between remote population fragments – is unlikely to be an effective approach in this case. Though inbreeding is a contributor to extinction risk, for static populations of 20 individuals or less, and for growing populations of 5 or less, extinction risk remains high (>5%) even once inbreeding is corrected. More effective strategies would be those that increase population size, either by re-establishing growth or by consolidating a number of smaller sub-populations, as these would be effective both in reducing inbreeding accumulation and in mitigating other chance-driven demographic and environmental risks arising from small size and isolation.

Female reproduction

Female reproductive output is the single most important contributor to growth in protected populations of Sumatran rhinos. Participants suggested a number of ways in which this may currently be compromised in remaining fragments: too much forest disturbance disrupting breeding behaviour; Allee effect preventing females from accessing mates with consequences for reproductive physiology; presence of disease; and inbreeding depression. Without assuming a specific mechanism, models were built to highlight the potential impact of depressed female reproduction on population performance.

On average, increasing female breeding rate to 25% (i.e. approximately 1 calf every 4 years) provides for a reasonable rate of positive growth (2-3%), though there remains much variation across iterations. Increasing breeding rate further, to 33% per year (approximately 1 calf every 3 years), not only increases the average rate of growth but greatly increases the certainty of this outcome. This is illustrated in Figure 6a, which shows 10 iterations of four models that differ only in the percentage of females breeding each year. At the 16% rate (A) growth is negative; at 20% (B) some iterations show growth but most show little or none; at 25% (C) potential trajectories lean towards strong positive growth but there is considerable divergence in outcome; and at 33% all trajectories move in the same direction and at similar rates.

In interpreting the results note that though likelihood of extinction is low for all but the 16% breeding rate, and though expected time to extinction, where it occurs, is long (>80 years), these models paint an optimistic picture as they do not include disease outbreaks, poaching, or natural or man-made catastrophes, and starting size (N=50) exceeds the estimates for most remaining sub-populations.

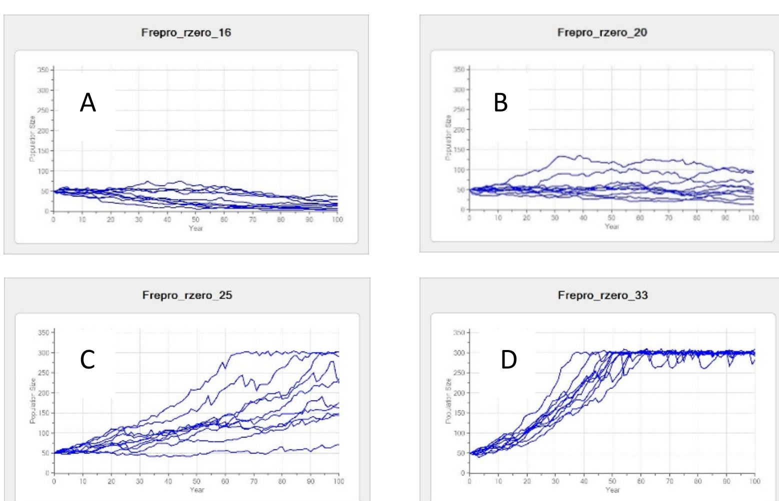
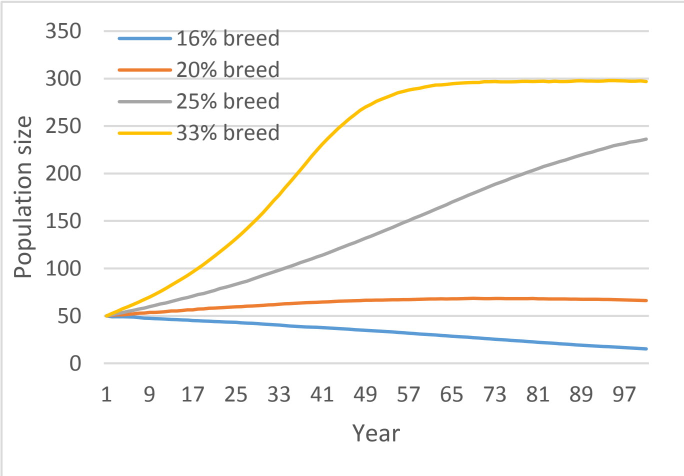


Figure 6a. Ten iterations of four models differing only in the annual percentage of females breeding: A=16%; B=20%; C=25%; D=33%.



Rate	P(Ex)	MTE (yrs)
16%	0.179	85
20%	0.015	81
25%	0.000	0
33%	0.000	0

Figure 6b. Comparison of expected population growth over time under different rates of female reproduction (16, 20, 25 and 33% of females breeding each year). Likelihood of extinction by year 100 and expected (mean) time to extinction (MTE) are given above.

Age structure and sex ratio

Small populations are vulnerable to chance fluctuations in sex-ratio and to the unstable age-structures that can result from threats that act disproportionately on particular age-classes. Where populations have been unable to breed for a period, or where juvenile survival has been high and recruitment low, this may producing an ageing population, exacerbating these problems.

Little is known about the age -structure and sex-ratio of remaining rhino populations. Models were built to explore the potential impact of these on the viability of different sized sub-populations.

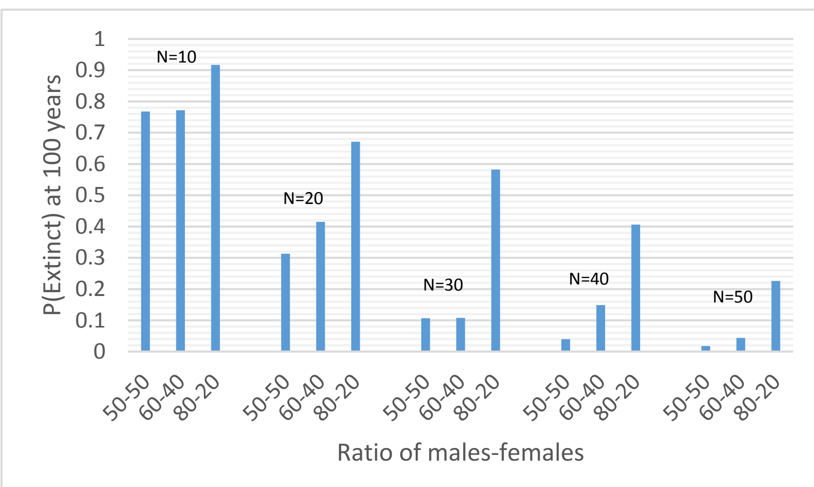


Figure 7. Impact of sex-ratio skew on 100-year extinction risk for different-sized populations.

Figure 7 shows the impact, on populations of 10, 20, 30, 40 and 50 individuals, of an initial sex-ratio bias of either 60-40 or 80-20. Compared to an even sex-ratio, a 60-40 skew generates a small increase in risk for all population sizes compared with an 80-20 skew, which generates a much larger shift in risk. Note that the larger the population size the less likely such a shift could have occurred by chance.

Three types of age structure skew were modelled: stable (animals are spread across all age-classes); over 20 years (animals are all 20 - 40 years old and are spread evenly across those age-classes); under 10 years (animals are all 0 – 10 years old and are spread evenly across those age-classes).

As shown in Figures 8a and b, the most optimistic age-structure is one comprising all animals younger than ten years, though its performance is similar to that produced by a stable age structure. Scenarios in which populations begin only with animals aged 20 years or more perform considerably less well. A long period with little breeding or recruitment could produce this ageing structure.

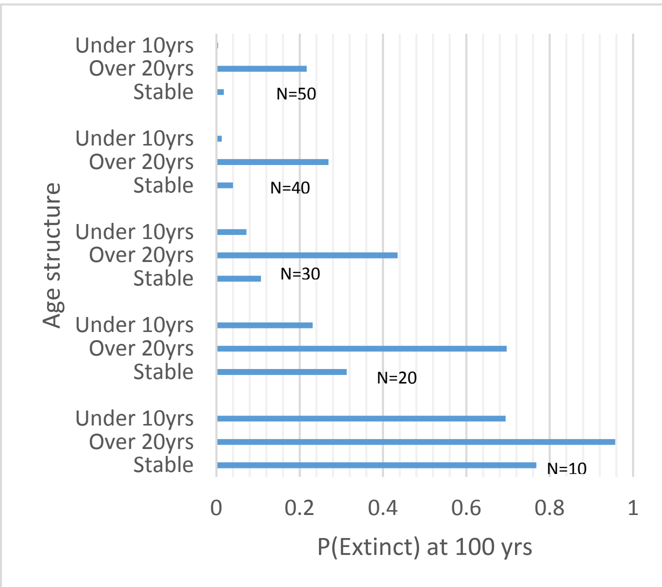


Figure 8a. Impact of age-structure skew on 100-year extinction risk, for different-sized populations.

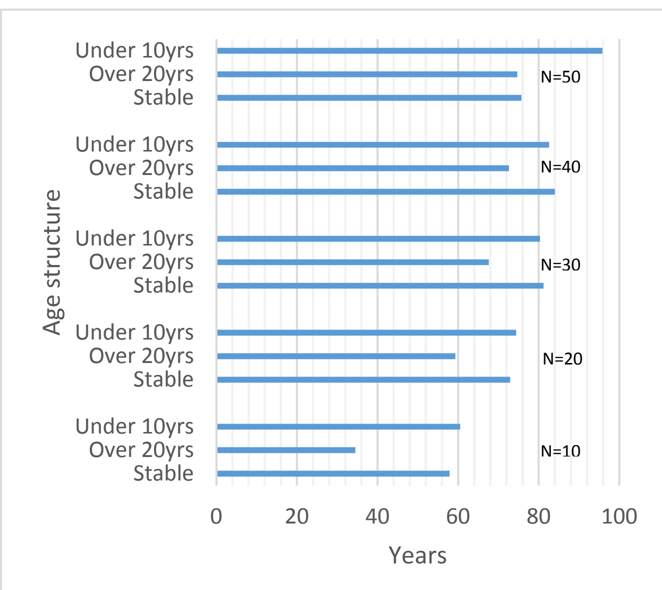


Figure 8b. Impact of age-structure skew on expected time to extinction, for different-sized populations.

Site-based Scenarios

Site-based scenarios were constructed and tested for each remaining site thought or known to contain rhinos. Given the uncertainty around numbers at each site, minimum, best guess and maximum estimates are tested in many of the scenarios.

Bukit Barisan Selatan (BBS)

Bukit Barisan Selatan includes two sub-populations: one occupying an Intensive Protection Zone (IPZ) and a second in Tambling about which little is known. Animals do not currently move between the two sites.

Scenarios were developed to consider the viability of the population within the Intensive Protection Zone. Taking a precautionary approach, all scenarios were based on the "zero growth" model. Worst case, best guess and optimistic population size estimates were considered, with and without periodic disease outbreaks, and at varied intensities of poaching. The rates of poaching considered were as follows:

- **Low poaching rate;** 0-2 individuals poached every 2 years
- **Medium poaching rate;** 0-4 individuals poached every year
- **High poaching rate;** 4-7 individuals poached each year for 1-2 years, with this event occurring every 4-8 years

Only one disease outbreak scenario was considered, in which the outbreak occurs approximately once every 20 years, causing 10% mortality and reducing breeding by 5%.

Consolidation of the two sub-populations of rhinos into a single population was considered; that is, the translocation of Tambling individuals into the IPZ. Factors implicated in keeping inter-birth intervals higher (and therefore growth rates low) might be expected to be mitigated within the IPZ. To explore this a range of inter-birth intervals (IBI) was also considered (IBI = 3, 4 and 5 years).

The IPZ is bounded by roads and this may impact carrying capacity. Scenarios were considered in which the estimated carrying capacity of 120 individuals was reduced to 90 and 60.

Table 7 describes all of the scenarios developed and provides a summary of the main results. Further details are provided below. In any tables, extinction risks ≥ 5% (i.e. one in 20 or more) are highlighted in red.

BBS – IPZ baselines

Figure 9 illustrates the performance of the three BBS baseline models: the "pessimistic" model with a starting population size of 15 individuals; the "best guess" model with a starting population of 22 individuals, and the "optimistic" model, with a starting population of 30 individuals.

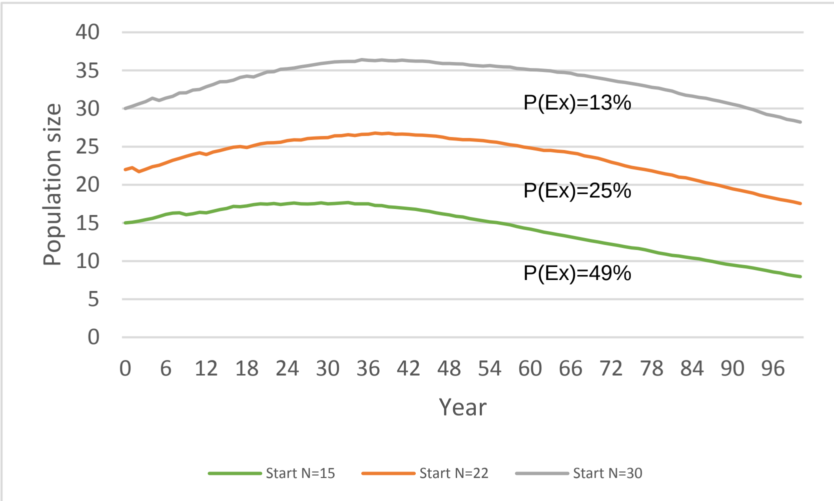


Figure 9. Projections for baseline BBS models with varied starting population sizes (N=15, 22 and 30)

Across the range of estimates modelled for BBS-IPZ, population size has a measurable impact on likelihood of extinction. At the lowest estimate (N=15) likelihood of extinction over the 100 year period is almost 50%; this risk is halved for starting sizes of N=22, and roughly halved again for starting sizes of N=30. Average times to extinction ranged from 69 years for N=15 to 79 years for N=30.

In summary, even the most optimistic scenario for BBS (with a starting size of N=30 and in the absence of disease outbreaks and poaching) shows a relatively high risk of extinction over the 100 year period considered.

BBS – IPZ and disease

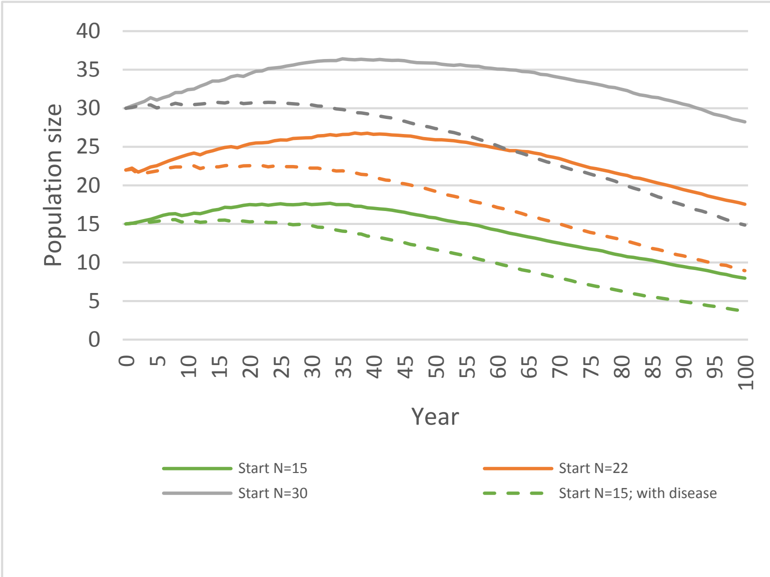
The baseline models are assumed to include some incidence of disease, incorporated within the age-specific mortality rates. The disease modelled here is in addition to that and takes the form of periodic outbreaks occurring with an average frequency of once every 20 years and resulting in 10% mortality and a 5% reduction in reproduction, in the year of occurrence. The impact is a reduction in population performance across all three scenarios considered (starting sizes of N=15, 22 and 30). Likelihood of extinction is increased in all three cases and expected time to extinction reduced (see Figure 10.).

BBS – IPZ and poaching

For each of the IPZ population estimates (n=15, 22, and 30), three levels of poaching intensity were considered:

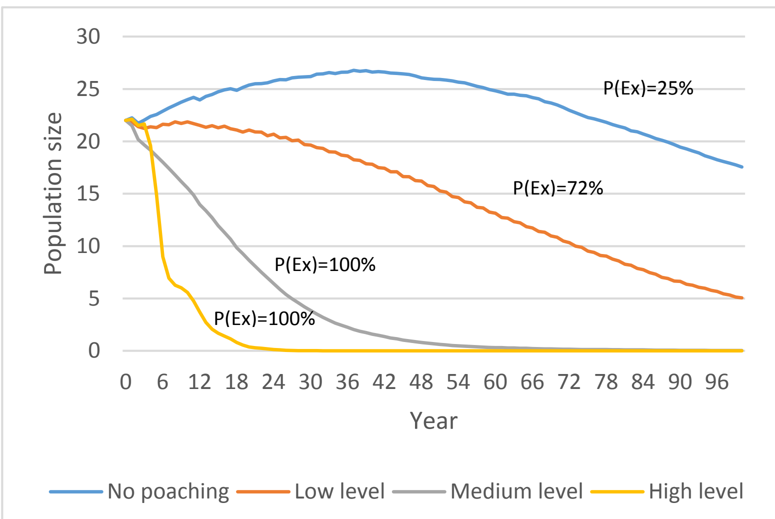
- **Low poaching rate;** 0-2 individuals poached every 2 years
- **Medium poaching rate;** 0-4 individuals poached every year
- **High poaching rate;** 4-7 individuals poached each year for 1-2 years, with this event occurring every 4-8 years

The results are illustrated in Figure 11.



Scenario	P(Extinct) @ 100 years	Mean Time to Extinction (yrs)
N=15	0.487	68.9
N=22	0.252	76.3
N=30	0.126	79.4
N=15; disease	0.687	64.6
N=22; disease	0.433	72.7
N=30; disease	0.293	77.6

Figure 10. Projections for 3 baseline BBS-IPZ models with and without periodic disease outbreaks. 100 year extinction probabilities and mean times to extinction shown above.



PoachingScenario (start N=22)	P(Extinct) @ 100 years	Mean Time to Extinction (yrs)
Zero	0.252	76.3
Low level	0.722	62.8
Med level	1.00	25.1
High level	1.00	12.5

Figure 11. Impact of 3 levels of poaching intensity on the "best guess" baseline (starting N=22). Extinction likelihood and mean time to extinction shown above for all 3 baselines.

The addition of any level of poaching increases extinction risk considerably and reduces expected time to extinction. At the highest poaching rate, expected time to extinction is only 12.5 years.

BBS disease and poaching

As illustrated in the above examples, both disease and poaching on their own can be expected to increase extinction risk and reduce time to extinction. The result of adding both to the most optimistic BBS-IPZ scenario (starting N=30) is illustrated in Figure 12.

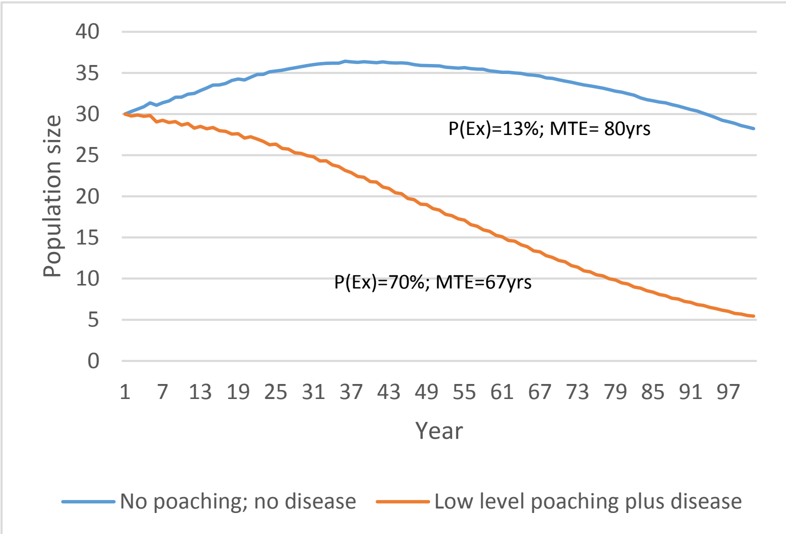


Figure 12. Impact of adding both disease and low level poaching to the most optimistic BBS-IPZ model (N=30). Extinction risk and mean time to extinction (MTE) shown.

Even under the most optimistic starting population size estimate, extinction risk over 100 years is high (70%) when both periodic disease outbreaks and low-level poaching (0-2 individuals taken every 2 years) are added.

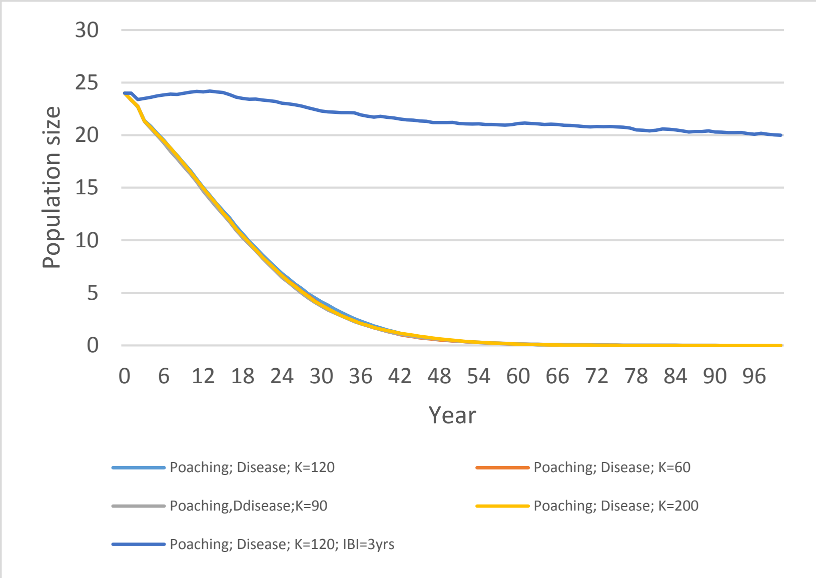
Addition of Tambling individuals

At its current size the IPZ population is vulnerable to a range of risk factors. The population at Tambling is much smaller and at much greater risk. A series of scenarios was developed to consider the effect of consolidation; that is, of translocating all remaining animals at Tambling to the IPZ. Estimates of the number of individuals at Tambling range from N=1–10, with a best guess value of N=2; the latter is used in the consolidation scenarios.

Consolidation scenarios were developed to consider the combined population in the presence of disease outbreaks and medium level poaching. In addition, assuming that consolidation and management within the IPZ could remove some of the factors that might reduce breeding rates, scenarios are run which reduce inter-birth interval (from 4 to 3 years). As a precaution, scenarios were also developed to consider the impact of varied carrying capacity; BBS has a number of roads that may reduce expected carrying capacity. K is modelled at 200, 120, 90 and 60.

The graph and table shown in Figure 13 illustrate the behaviour of the models under this series of consolidation scenarios. In all but one of the scenarios modelled (that is, with IBI=3 years), medium level poaching causes extinction of all populations in this size range over the 100 year period, with average time to extinction of approximately 27 years. Carrying capacity has no impact on either the risk of extinction or the average time to extinction, because populations do not grow to reach even the smaller of the capacities considered. Where female breeding rate is increased (IBI = 3 years), the resulting population growth is sufficient to offset some of the pressure exerted by poaching and disease. Despite this, 74% of these populations go extinct over the period, taking an average of 44 years to do so.

Figure 13 illustrates the addition of Tambling animals to the IPZ under a range of conditions.



IPZ & Tambling with disease and med level poaching	P(Extinct) @ 100 years	MTE (yrs)
K=60	1.00	27.2
K=90	1.00	26.8
K=120	1.00	27.7
K=200	1.00	27.2
K=120; IBI=3yrs	0.742	43.7

Figure 13. Potential impact of adding (2) Tambling individuals to the BBS-IPZ under a regime of periodic disease outbreaks, medium level poaching, varied K and with inter-birth interval decreased from 4 to 3 years.

BBS – IPZ and metapopulation management

Management of BBS-IPZ as part of a wider meta-population was considered, to assess whether viability at the BBS-IPZ site could be improved by the addition of 5 and 10 individuals from another site. The results are shown in Figure 14.

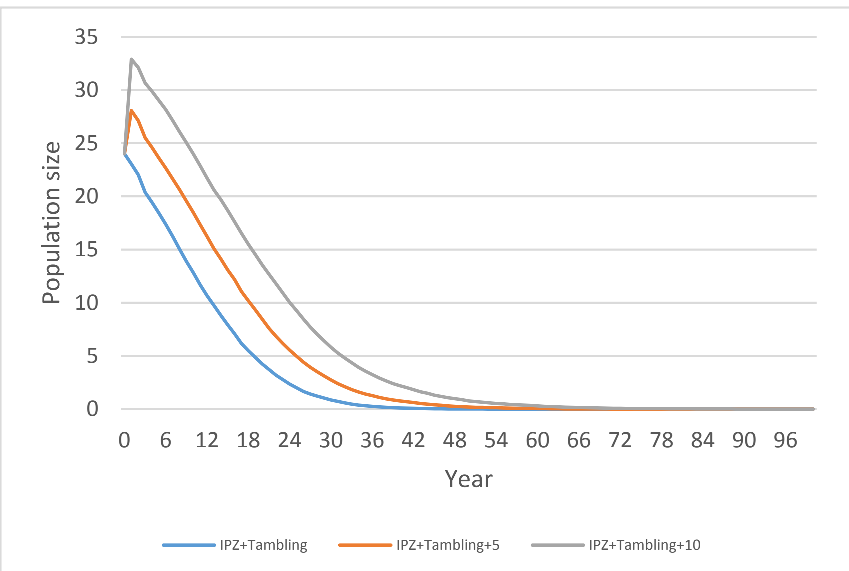


Figure 14. Potential impact of adding 5 and 10 individuals to a consolidated IPZ plus Tambling population under medium level poaching and in the presence of periodic disease outbreaks.

As illustrated, the addition of 5 or 10 individuals to the consolidated IPZ plus Tambling population, would not be sufficient to offset the extinction risk from medium level poaching.

Metapopulation Scenarios

In addition to the BBS metapopulation scenarios additional scenarios for the management of all remaining Sumatran rhinos as a metapopulation were explored. These were:

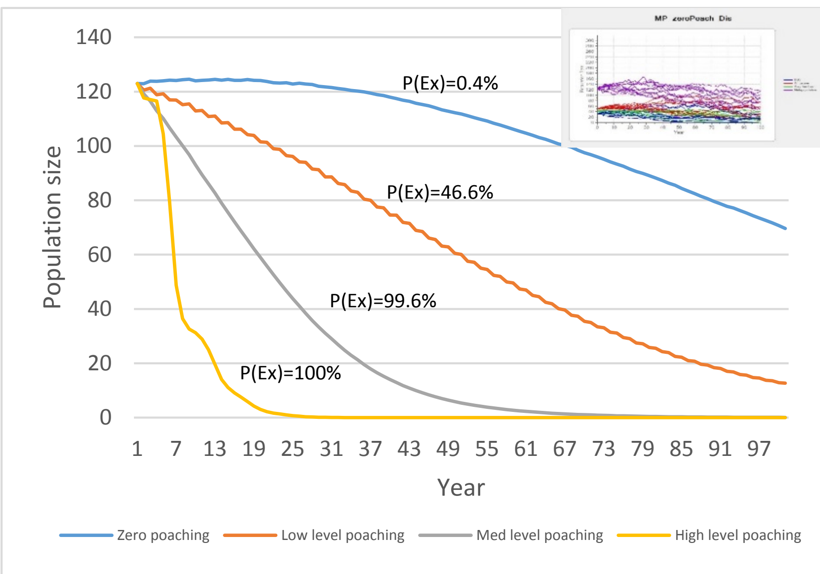
- consolidation of remaining rhinos at three sites: with 32 at BBS, 41 at Way Kambas and 50 at Gunung Leuser.
- consolidation at two hypothetical sites, each holding 64 individuals.

The viability of these was tested in the face of disease, low, medium and high-intensity poaching, and with and without gene-flow between sites.

Metapopulation management with three sites

Under zero poaching and with no inter-site movement of animals, the 3-site meta-population shows a low likelihood of extinction over the 100 year period considered (P(Extinct @100 years)=0.004; MTE=96.5). However on average the modelled populations declined over time from N=120 to around N=70, with sub-populations showing extinction risks of 6 and 7% (Gunung Leuser and Way Kambas) to 21% (BBS).

Introducing annual inter-site movements in which each site receives two individuals from another site and also sends two animals to another, different site, increases overall meta-population gene diversity at 100 years (average GD increases from 0.9356; allele number= 30.12 to GD= 0.9519; allele number=36.53). There is no clear directional change in extinction risk.



3-site metapop. at varied poaching intensity	P(Extinct) @ 100 years	MTE (yrs)
Zero	0.004	96.5
Low level	0.466	82.8
Med level	0.996	46.4
High level	1.000	18.7

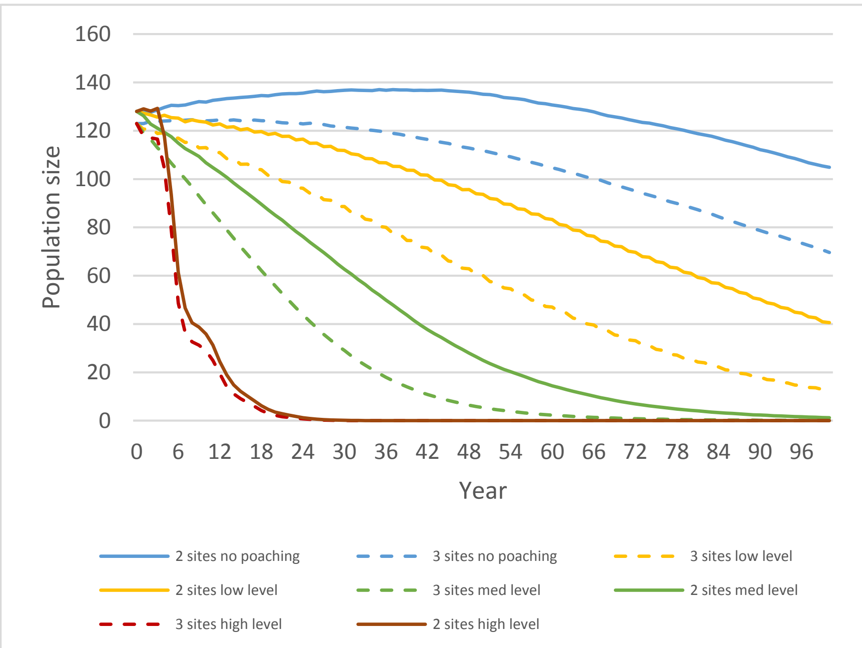
Figure 15. Impact of zero, low, medium and high level poaching on performance of a 3-site meta-population with no inter-site movement. Likelihood of extinction after 100 years and mean time to extinction (MTE) are shown above.

Metapopulation management with two sites

Figure 16 compares the performance of 3 and 2-site meta-populations under zero, low-level, medium level and high level poaching.

On average, overall population size remains larger for the 2-site scenarios, except for in the high-level poaching models where 2 and 3-site projections follow a similar, rapidly downhill path. The ability of the 2-site metapopulation to sustain larger overall size, for longer, may be attributable to the greater instability of the smaller sized units within the 3-site model (starting N≤50 at all 3 sites) due to demographic stochasticity and inbreeding, exacerbated by periodic disease outbreaks. These effects would be expected to be less acutely felt in the 2-site meta-population where starting sub-population sizes are larger (starting N=64).

The greatest difference between 2 and 3 site metapopulations is seen at low levels of poaching, where extinction risk is noticeably higher for the 3-site scenarios (P(Ex)=47% for 3 sites versus 13% for 2 sites). This is a likely reflection of the period considered (100 years). That is, under low-level poaching both 2 and 3 site metapopulations show steady decline, but the larger overall sizes maintained by the 2-site models would be expected to delay many extinction events to beyond the 100 year threshold illustrated.



# sites & poaching intensity	P(Extinct) @ 100 years	MTE (yrs)
2-zero	0.000	-
3-zero	0.004	96.5
2-low level	0.129	87.0
3-low level	0.466	82.8
2-med level	0.948	62.0
3-med level	0.996	46.4
2-high level	1.000	20.2
3-high level	1.000	18.7

Figure 16. Comparison between 2-site (solid lines) and 3-site (dashed lines) metapopulation performance at zero, low, medium and high level poaching. Likelihood of extinction after 100 years and mean time to extinction (MTE) are shown above.

Captive Population Scenarios

The captive facility at Way Kambas has the potential to provide complete protection from poaching and to act quickly to restrict the impact of disease outbreaks. Further, captive conditions are expected to cushion inbreeding effects (O'Grady et al., 2006). Though not yet tested it may also be possible to manipulate female breeding success. Figure 17 compares the expected performance of three hypothetical populations beginning with the age, gender and genetic composition of the current captive population; one under an ideal captive management regime (reduced inbreeding impact, inter-birth interval of 3 years); the other two based on the wild baseline models (one with the ability to grow, the other without). Poaching and disease are excluded from all three scenarios and carrying capacity is set at K=10.

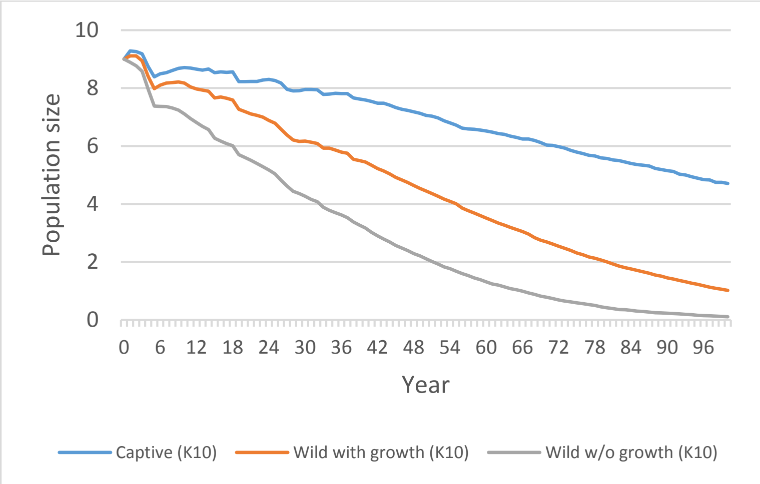


Figure 17. Potential performance of captive population compared with wild populations of the same size and composition. Extinction risks and mean times to extinction (MTE) shown below.

	P(Extinct) @ 100 years	MTE (yrs)
Captive	0.445	58.0
Wild with growth	0.846	53.6
Wild without growth	0.982	40.9

As illustrated, under the right conditions the captive population could outperform wild populations of similar size, structure and capacity constraints. The captive models showed positive growth (r=0.017) compared to negative growth in the wild models (r=-0.006 (with growth) and r=-0.021 (w/o growth)), and delivered lower extinction risks and longer times to extinction. However, at the starting population size and carrying capacity modelled (N=9, K=10), risk of extinction is high from demographic, environmental and genetic risks (inbreeding depression). The viability of any population of this size would be reliant always on supplementation or exchange with larger populations.

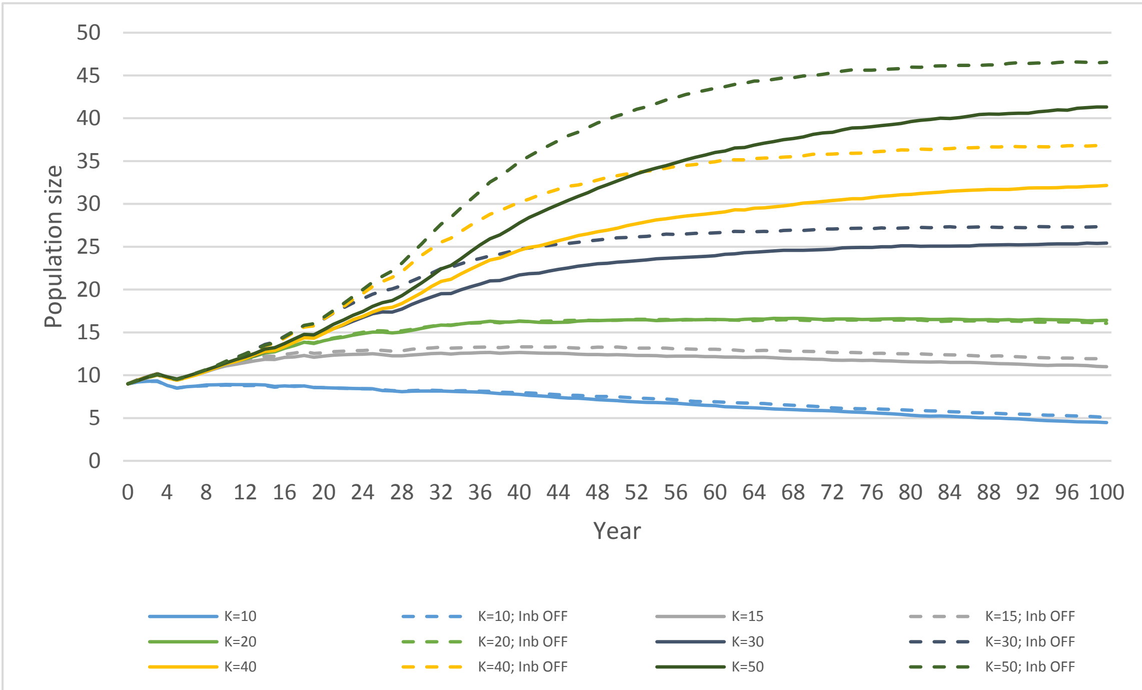
Inbreeding

Figure 18 illustrates the impact of inbreeding depression on captive population performance, for a range of carrying capacities (K=10, 15, 20, 30, 40, 50). Where captive carrying capacity is 20 individuals or fewer, the exclusion of inbreeding depression from the models has little impact on extinction risk; the threats posed by demographic and environmental uncertainty are already too great. Beyond K=20 inbreeding becomes a more significant risk factor, exerting downward pressure on population sizes and contributing to extinction.

The addition of two adult rhinos (one male and one female) every 10 years was sufficient to reduce extinction risk for K=10 from 51% to 8%, and for K≥30 to zero.

Harvesting for release

Models were constructed to investigate the potential for using a well-protected, closely managed captive population as a net producer of animals for release to wild populations. Scenarios were constructed which explored the size of annual harvest possible from captive populations with carrying capacities of 10, 20, 30, 40 and 50. Only individuals aged 6 and above were harvested. In all cases the starting population was assigned the gender, age structure and genetic characteristics of the current captive population. Inter-birth interval was set to three years and two unrelated adults were brought in every 10 years to manage inbreeding.



Scenario	P(Ex)@100 years	MTE (yrs)	Scenario	P(Ex)@100 years	MTE (yrs)
K=10	0.511	53.6	K=10; No Inb	0.503	50.8
K=15	0.195	54.8	K=15; No Inb	0.187	55.5
K=20	0.121	45.1	K=20; No Inb	0.137	48.1
K=30	0.101	39.5	K=30; No Inb	0.063	26.6
K=40	0.135	37.7	K=40; No Inb	0.057	28.9
K=50	0.107	39.4	K=50; No Inb	0.053	24.3

Figure 18. Performance of captive models with different carrying capacities. For each K value inbreeding depression is both included (solid lines) and excluded (dashed lines). Extinction risks and mean times to extinction (MTE) shown left.

Figure 19a illustrates the allowable harvest of adult rhinos from one model iteration, for a captive carrying capacity set to K=10. As illustrated the harvest is occasional and of one or two individuals only. Figure 19b shows the results for a single iteration with a carrying capacity of 50. Note that the first 20-25 years are spent growing to capacity, but once there the harvest is regular and ranges in size from 1-6 individuals. Figure 19c illustrates the harvests expected from captive carrying capacities of 15, 20, 30, and 40 individuals.

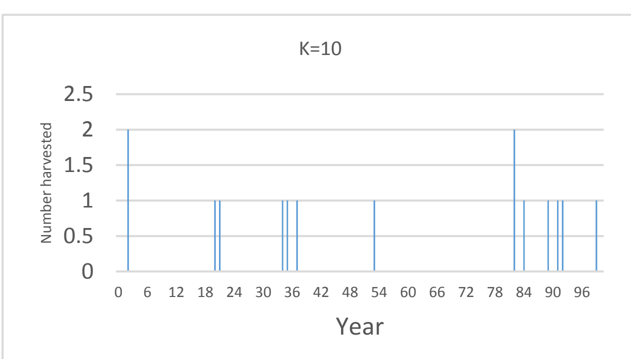


Figure 19a. Example of an allowable harvest over 100 years for a captive population beginning with 9 individuals with a carrying capacity of K=10. Inter-birth interval is 3 years and 2 unrelated rhinos are added every 10 years to reduce inbreeding.

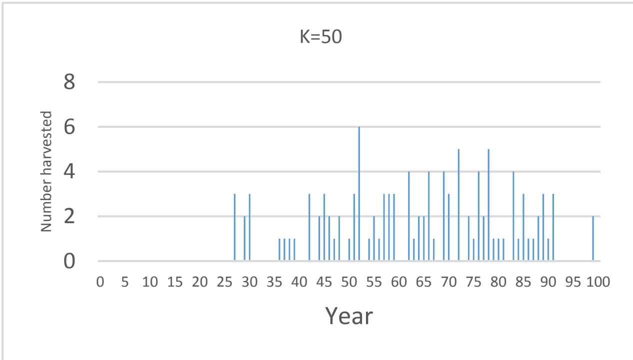


Figure 19b. Example of an allowable harvest over 100 years for a captive population beginning with 9 individuals with a carrying capacity of K=50. Inter-birth interval is 3 years and 2 unrelated rhinos are added every 10 years to reduce inbreeding.

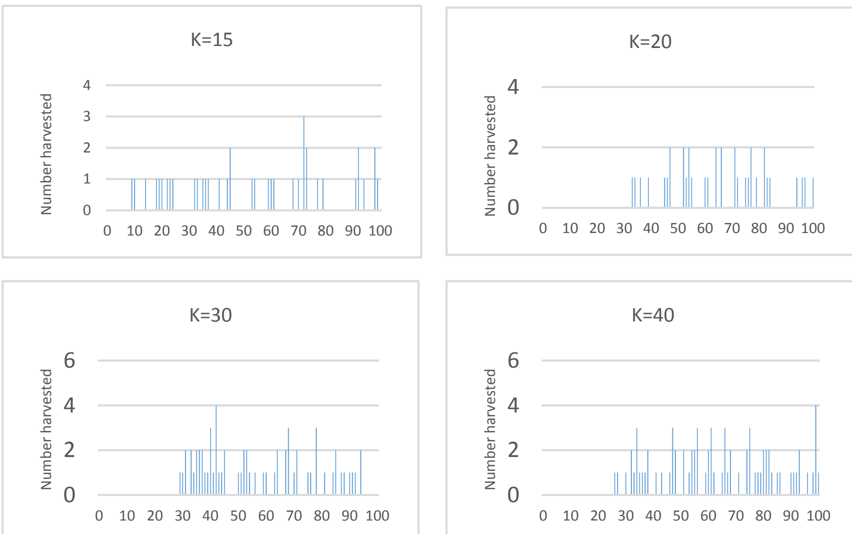


Figure 19c. Examples of allowable harvests over 100 years for captive population beginning with 9 individuals and with carrying capacities of K=15, 20, 30 & 40. Inter-birth interval is 3 years and 2 unrelated rhinos are added every 10 years to reduce

Average annual harvest rates for the different carrying capacities were calculated across five model iterations. Calculations were taken from the average point at which populations reached the designated carrying capacity. The results are displayed in Table 5. As carrying capacity increases both the mean and variation in harvest size increases, from around 1 rhino every 5 years at K=10 to around 1 rhino per year at K=50.

Table 5. Expected annual harvest for captive models with different carrying capacities. Means are across 5 iterations.

Captive carrying capacity	Mean time to K (from start N=9) (yrs)	Annual harvest (# rhinos) once at K (Mean (S.D.))
K=10	1	0.22 (0.45)
K=15	10	0.34 (0.59)
K=20	18	0.41 (0.65)
K=30	26	0.63 (0.88)
K=40	32	0.82 (1.12)
K=50	32	1.03 (1.34)

To summarize the modeling results described above, for the foreseeable future the viability of all remaining rhino populations will depend on complete protection from poaching. Even with this in place, populations numbering 15 or fewer are at risk to demographic, environmental and genetic uncertainty and would be expected to benefit from consolidation. For populations numbering between 15 and 40, ability to persist will be closely tied to the ability to grow, which is expected to hinge on female reproductive performance. Factors affecting this need to be better understood, monitored and managed until consistent growth is secured. Populations of 40 or more are expected to show greater resilience over the time period considered, but only in the absence of human-mediated threats. Even with consolidation at the three sites, further expansion in numbers will be needed over time, coupled with low-intensity metapopulation management, to moderate the longer-term issues of genetic deterioration and environmental change.

Vortex Results Summary

Table 6 summarises the results from all of the scenarios tested. Columns are as follows:

Det-r	**Deterministic growth rate**
Stoch-r	Stochastic growth rate
SD(r)	Standard deviation in the above
PE	Probability of extinction over the 100 year period
N-extant	Mean final population size across iteration in which the population survived
SD(Next)	Standard deviation in the above
N-all	Mean final population size across all iterations
SD(Nall)	Standard deviation in the above
GeneDiv	Mean final expected heterozygosity ("gene diversity")
AlleleN	Mean final number of alleles retained (each founder begins with 2 unique alleles)
MeanTE	Average time to first extinction across iterations in which the populations goes extinct

Table 6. Summary of modelling results across all scenarios tested

Scenario	det-r	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	AlleleN	MeanTE
Baselines											
SRhino_Base_r3	0.031	0.026	0.035	0.000	295.5	16.01	295.5	16.01	0.9612	44.61	0.0
SRhino_Base_rzero	0.008	0.000	0.048	0.013	67.0	42.71	66.1	43.09	0.9082	20.23	81.2
SRhino_Base_captive	0.031	0.009	0.089	0.310	57.5	49.55	39.8	48.94	0.7341	5.90	44.5
Impact of starting population size at two different rates of growth											
Size_rzero_5	0.008	-0.012	0.126	0.960	6.6	4.2	0.3	1.6	0.5413	3.30	36.3
Size_rzero_10	0.008	-0.013	0.103	0.742	10.0	8.5	2.8	6.1	0.6589	4.61	58.2
Size_rzero_15	0.008	-0.011	0.090	0.517	15.3	13.4	7.7	11.9	0.7355	6.31	67.6
Size_rzero_20	0.008	-0.009	0.079	0.326	19.1	15.1	13.1	15.1	0.7702	7.58	72.0
Size_rzero_25	0.008	-0.007	0.072	0.202	25.5	22.3	20.5	22.2	0.8046	9.25	76.1
Size_rzero_30	0.008	-0.004	0.064	0.091	33.6	26.0	30.7	26.4	0.8406	11.65	84.7
Size_rzero_35	0.008	-0.003	0.059	0.074	39.8	30.6	36.9	31.1	0.8576	13.11	81.1
Size_rzero_40	0.008	-0.003	0.056	0.048	45.5	31.8	43.3	32.5	0.8743	14.97	81.6
Size_rzero_45	0.008	-0.001	0.052	0.028	57.2	38.2	55.6	39.0	0.8929	17.88	84.2
Size_rzero_50	0.008	0.000	0.048	0.013	67.8	43.7	66.9	44.1	0.9074	20.26	85.5
Size_r3_5	0.031	-0.001	0.117	0.726	16.1	17.3	4.6	11.5	0.6149	3.99	45.7
Size_r3_10	0.031	0.010	0.076	0.158	55.5	50.2	46.8	50.2	0.7855	8.31	65.4
Size_r3_15	0.031	0.016	0.060	0.036	109.4	76.6	105.5	77.9	0.8569	12.63	69.4
Size_r3_20	0.031	0.020	0.050	0.004	170.4	89.8	169.7	90.2	0.8976	17.76	73.3
Size_r3_25	0.031	0.022	0.045	0.001	220.5	81.65	220.3	81.8	0.9214	22.37	93.0
Size_r3_30	0.031	0.024	0.042	0.001	257.7	64.7	257.4	65.2	0.9369	27.61	73.0
Size_r3_35	0.031	0.025	0.039	0.000	276.8	49.0	276.8	49.0	0.9460	32.20	0.0
Size_r3_40	0.031	0.025	0.037	0.000	288.2	33.2	288.2	33.2	0.9530	36.48	0.0
Size_r3_45	0.031	0.026	0.036	0.000	292.6	23.5	292.6	23.5	0.9570	40.47	0.0
Size_r3_50	0.031	0.027	0.035	0.000	296.1	14.0	296.1	14.0	0.9617	44.74	0.0
Impact of adding disease outbreaks at 3 different frequencies of occurrence											
Disease_rzero_freq2	0.007	-0.001	0.051	0.019	58.8	40.1	57.7	40.5	0.8984	18.67	89.5
Disease_rzero_freq5	0.005	-0.003	0.054	0.036	49.8	35.1	48.1	35.6	0.8908	17.06	79.2
Disease_rzero_freq10	0.002	-0.007	0.060	0.061	37.1	25.5	34.9	26.2	0.8729	14.65	82.8
Impact of increasing female reproductive rates											
Frepro_rzero_16	-0.006	-0.016	0.066	0.190	18.2	12.9	15.0	13.4	0.8251	10.09	84.0
Frepro_rzero_20	0.008	0.000	0.048	0.016	67.8	43.0	66.7	43.5	0.9068	20.23	80.3
Frepro_rzero_25	0.022	0.016	0.039	0.000	231.8	75.4	231.8	75.4	0.9485	34.93	0.0
Frepro_rzero_33	0.041	0.036	0.035	0.000	298.4	4.7	298.4	4.7	0.9634	47.30	0.0
Allee effect impacts											
Allee_rzero_NoAllee	0.008	0.000	0.049	0.013	64.4	40.5	63.6	40.9	0.9061	19.71	84.4
Allee_rzero_Allee_1	-0.007	-0.017	0.068	0.232	16.6	12.5	13.0	12.8	0.8197	9.68	82.9
Allee_rzero_Allee_2	-0.008	-0.020	0.071	0.320	14.8	11.7	10.3	11.7	0.8074	9.15	81.6
Allee_rzero_Allee_4	-0.010	-0.024	0.075	0.478	13.0	10.5	7.1	9.9	0.8054	8.62	81.1
Age structure impacts											
Agestrut_rzero_Allover20_N10	0.008	-0.030	0.129	0.955	6.0	3.9	0.4	1.5	0.5660	3.29	35.1
Agestrut_rzero_Allover20_N20	0.008	-0.021	0.102	0.690	10.6	8.6	3.5	6.8	0.6658	4.89	59.5
Agestrut_rzero_Allover20_N30	0.008	-0.016	0.087	0.440	17.1	14.7	9.8	13.8	0.7501	6.99	67.9

Scenario	det-r	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	AlleleN	MeanTE
Agestrut_rzero_Allover20_N40	0.008	-0.014	0.077	0.281	23.4	19.2	17.0	19.2	0.7917	8.78	71.9
Agestrut_rzero_Allover20_N50	0.008	-0.014	0.075	0.221	25.9	21.8	20.4	21.9	0.8032	9.63	73.9
Agestrut_rzero_Allunder10_N10	0.008	-0.011	0.100	0.677	10.6	8.6	3.6	6.9	0.6785	4.98	59.9
Agestrut_rzero_Allunder10_N20	0.008	-0.006	0.075	0.254	22.9	19.0	17.2	19.1	0.7942	8.57	74.9
Agestrut_rzero_Allunder10_N30	0.008	-0.001	0.058	0.048	41.6	31.5	39.6	31.9	0.8617	13.71	78.8
Agestrut_rzero_Allunder10_N40	0.008	0.002	0.050	0.016	63.7	42.2	62.7	42.5	0.9038	19.16	89.1
Agestrut_rzero_Allunder10_N50	0.008	0.003	0.044	0.004	85.9	48.3	85.6	48.5	0.9263	24.82	83.0
Sex-ratio bias impacts											
SR_rzero_N10_60_40	0.008	-0.014	0.104	0.798	9.85	7.86	2.22	5.26	0.6760	4.76	56.7
SR_rzero_N10_80_20	0.008	-0.022	0.116	0.921	8.18	7.40	0.73	3.03	0.6055	3.94	41.9
SR_rzero_N20_60_40	0.008	-0.011	0.084	0.433	17.61	14.63	10.23	13.90	0.7560	6.97	69.1
SR_rzero_N20_80_20	0.008	-0.021	0.099	0.708	11.47	10.22	3.54	7.53	0.6823	5.10	57.1
SR_rzero_N30_60_40	0.008	-0.004	0.063	0.116	34.75	26.03	30.85	26.74	0.8430	11.58	77.7
SR_rzero_N30_80_20	0.008	-0.020	0.088	0.539	15.92	15.59	7.52	13.14	0.7353	6.56	62.2
SR_rzero_N40_60_40	0.008	-0.008	0.065	0.136	31.57	26.81	27.40	27.05	0.8330	11.32	78.6
SR_rzero_N40_80_20	0.008	-0.018	0.082	0.425	19.06	16.37	11.21	15.43	0.7724	7.82	69.4
SR_rzero_N50_60_40	0.008	-0.004	0.054	0.047	50.74	36.18	48.42	36.84	0.8858	16.49	82.1
SR_rzero_N50_80_20	0.008	-0.015	0.072	0.244	25.60	22.56	19.53	22.34	0.8100	9.69	73.4
Inbreeding impacts with varied population size and at 2 different growth rates											
Size_rzero_5NoInb	0.008	0.001	0.119	0.736	25.2	19.4	6.72	14.89	0.5693	3.69	31.5
Size_rzero_10_Noinb	0.008	0.002	0.092	0.371	32.3	26.9	20.44	26.34	0.7019	5.72	51.4
Size_rzero_15NoInb	0.008	0.003	0.079	0.210	41.0	31.6	32.52	32.58	0.7600	7.52	59.5
Size_rzero_20_Noinb	0.008	0.004	0.070	0.116	50.0	36.8	44.25	38.04	0.8065	9.55	66.0
Size_rzero_30_Noinb	0.008	0.005	0.058	0.040	70.7	47.3	67.95	48.33	0.8619	13.97	70.8
Size_rzero_40NoInb	0.008	0.006	0.050	0.013	90.9	55.9	89.68	56.45	0.8972	18.39	77.6
Size_rzero_50NoInb	0.008	0.006	0.045	0.004	112.6	62.4	112.18	62.64	0.9174	22.95	90.5
Size_r3_5NoInb	0.031	0.024	0.098	0.334	116.4	81.1	77.58	86.22	0.6562	4.80	29.6
Size_r3_10_NoInb	0.031	0.028	0.064	0.038	196.9	92.6	189.40	98.27	0.8169	9.89	42.2
Size_r3_15_NoInb	0.031	0.029	0.054	0.003	234.8	82.3	234.08	83.19	0.8740	14.29	64.3
Size_r3_20_NoInb	0.031	0.029	0.047	0.002	267.0	61.0	266.50	62.08	0.9076	19.38	64.5
Size_r3_30_NoInb	0.031	0.029	0.041	0.000	289.3	32.3	289.25	32.29	0.9375	28.17	0.0
Size_r3_40_NoInb	0.031	0.030	0.037	0.000	297.5	10.4	297.47	10.35	0.9532	37.15	0.0
Size_r3_50_NoInb	0.031	0.030	0.035	0.000	298.1	7.2	298.07	7.16	0.9601	44.12	0.0
Poaching 0-2 every 2 years, 1-3 and 0-4 every year, and 4-7 for 1-2 years, every 4-8 years, at different population sizes											
Poach1-3_rzero_N10	0.008	-0.101	0.176	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	11.6
Poach1-3_rzero_N20	0.008	-0.068	0.135	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	23.8
Poach1-3_rzero_N30	0.008	-0.050	0.112	0.992	20.9	12.2	0.2	2.1	0.8197	9.50	38.4
Poach1-3_rzero_N40	0.008	-0.038	0.098	0.949	21.8	22.6	1.2	7.0	0.8261	10.02	52.5
Poach1-3_rzero_N50	0.008	-0.032	0.087	0.853	23.0	22.9	3.6	12.0	0.8439	11.58	62.5
Poach1-3_rzero_N60	0.008	-0.025	0.079	0.702	36.9	32.5	11.2	24.4	0.8796	15.76	69.0
Poach1-3_rzero_N70	0.008	-0.021	0.071	0.545	41.0	32.9	18.9	30.0	0.8895	17.44	73.3
Poach1-3_rzero_N80	0.008	-0.016	0.063	0.367	50.7	42.1	32.3	41.3	0.9046	20.44	77.9
Poach1-3_rzero_N90	0.008	-0.012	0.057	0.244	68.3	52.6	51.8	54.2	0.9207	24.76	81.8

Scenario	det-r	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	AlleleN	MeanTE
Poach0-2_2yrs_rzero_N10	0.008	-0.051	0.153	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	21.0
Poach0-2_2yrs_rzero_N20	0.008	-0.034	0.114	0.975	14.0	9.5	0.4	2.7	0.7728	7.44	43.8
Poach0-2_2yrs_rzero_N30	0.008	-0.026	0.096	0.824	23.6	24.2	4.3	13.5	0.8117	9.45	59.6
Poach0-2_2yrs_rzero_N40	0.008	-0.019	0.081	0.584	26.5	23.0	11.2	19.7	0.8394	11.35	69.0
Poach0-2_2yrs_rzero_N50	0.008	-0.014	0.070	0.372	37.0	30.3	23.4	29.7	0.8644	14.29	75.3
Poach0-2_2yrs_rzero_N60	0.008	-0.009	0.060	0.211	51.8	40.1	41.1	41.3	0.8945	18.47	79.9
Poach0-2_2yrs_rzero_N70	0.008	-0.006	0.053	0.119	65.0	45.9	57.4	47.8	0.9137	22.20	82.9
Poach0-2_2yrs_rzero_N80	0.008	-0.004	0.048	0.057	83.6	57.6	78.7	59.1	0.9289	26.99	84.3
Poach0-2_2yrs_rzero_N90	0.008	-0.002	0.044	0.026	97.9	61.2	95.4	62.4	0.9382	30.76	82.9
Poach0-4_yr_rzero_N10	0.008	-0.136	0.207	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	9.0
Poach0-4_yr_rzero_N20	0.008	-0.097	0.157	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	16.7
Poach0-4_yr_rzero_N30	0.008	-0.070	0.131	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	27.1
Poach0-4_yr_rzero_N40	0.008	-0.059	0.118	0.998	26.0	18.4	0.1	1.3	0.9060	16.00	35.7
Poach0-4_yr_rzero_N50	0.008	-0.047	0.105	0.983	32.2	19.7	0.6	4.9	0.8917	15.35	47.0
Poach0-4_yr_rzero_N60	0.008	-0.042	0.098	0.952	26.2	24.2	1.3	7.7	0.8647	13.58	54.7
Poach0-4_yr_rzero_N70	0.008	-0.035	0.088	0.851	39.4	42.4	6.0	21.5	0.8799	16.19	60.5
Poach0-4_yr_rzero_N80	0.008	-0.030	0.082	0.747	37.4	35.2	9.7	24.0	0.8923	17.30	69.4
Poach0-4_yr_rzero_N90	0.008	-0.026	0.076	0.635	47.3	41.2	17.5	33.6	0.9046	20.53	73.2
Poach4-7_1_2yr_Int4_8_rzero_N10	0.008	-0.095	0.319	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	9.6
Poach4-7_1_2yr_Int4_8_rzero_N20	0.008	-0.123	0.334	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	12.2
Poach4-7_1_2yr_Int4_8_rzero_N30	0.008	-0.129	0.346	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	14.1
Poach4-7_1_2yr_Int4_8_rzero_N40	0.008	-0.133	0.350	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	15.0
Poach4-7_1_2yr_Int4_8_rzero_N50	0.008	-0.134	0.343	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	15.8
Poach4-7_1_2yr_Int4_8_rzero_N60	0.008	-0.137	0.337	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	16.6
Poach4-7_1_2yr_Int4_8_rzero_N70	0.008	-0.136	0.330	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	17.7
Poach4-7_1_2yr_Int4_8_rzero_N80	0.008	-0.134	0.323	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	18.5
Poach4-7_1_2yr_Int4_8_rzero_N90	0.008	-0.134	0.322	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	19.8
Bukit Barisan Selatan											
BasePess_IPZ	0.008	-0.010	0.090	0.487	15.0	14.0	8.0	12.4	0.7228	6.11	68.9
BaseBG_IPZ	0.008	-0.007	0.075	0.252	23.2	18.5	17.6	18.8	0.7888	8.54	76.3
BaseOpt_IPZ	0.008	-0.005	0.065	0.126	32.2	24.2	28.2	24.9	0.8352	11.28	79.4
BasePess_Tambling	0.008	0.000	0.000	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	1.0
BaseBG_Tambling	0.008	0.012	0.134	0.999	5.0	0.0	0.0	0.2	0.4200	2.00	17.2
BaseOpt_Tambling	0.008	-0.013	0.104	0.767	10.2	8.4	2.6	5.9	0.6678	4.70	57.6
Pess_IPZ_Pch0-2_2yrs	0.008	-0.024	0.107	0.909	13.5	12.2	1.3	5.3	0.7252	6.03	49.4
BG_IPZ_Pch0-2_2yrs	0.008	-0.019	0.091	0.722	17.4	14.4	5.1	10.8	0.7793	7.62	62.8
Opt_IPZ_Pch0-2_2yrs	0.008	-0.015	0.079	0.498	25.2	22.2	12.9	20.1	0.8168	9.80	70.4
Pess_IPZ_Pch0-4_yr	0.008	-0.079	0.148	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	17.9
BG_IPZ_Pch0-4_yr	0.008	-0.062	0.130	0.999	22.0	0.0	0.0	0.7	0.8368	9.00	27.3
Opt_IPZ_Pch0-4_yr	0.008	-0.049	0.112	0.994	15.7	8.0	0.1	1.4	0.8456	9.83	38.1
Pess_IPZ_Pch0-2_2yrs_dis	0.003	-0.031	0.117	0.973	10.2	7.9	0.3	2.1	0.6994	5.04	43.5
BG_IPZ_Pch0-2_2yrs_dis	0.003	-0.026	0.103	0.875	12.6	10.1	1.7	5.5	0.7562	6.50	57.1
Opt_IPZ_Pch0-2_2yrs_dis	0.003	-0.022	0.092	0.699	17.5	15.6	5.4	11.7	0.7812	8.20	66.9
Pess_IPZ_dis	0.003	-0.016	0.100	0.687	11.1	10.0	3.7	7.5	0.7015	5.46	64.6

Scenario	det-r	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	AlleleN	MeanTE
BG_IPZ_dis	0.003	-0.013	0.088	0.433	15.3	13.5	8.9	12.6	0.7448	6.83	72.7
Opt_IPZ_dis	0.003	-0.012	0.079	0.293	20.7	17.4	14.9	17.2	0.7968	9.00	77.6
Pess_IPZ_Pch0-4_y_dis	0.003	-0.085	0.154	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	16.7
BG_IPZ_Pch0-4_yr_dis	0.003	-0.069	0.136	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	25.1
Opt_IPZ_Pch0-4_yr_dis	0.003	-0.056	0.120	0.997	17.7	4.9	0.1	1.0	0.8515	10.67	34.5
Pess_IPZ_Tamb_MedPchDis_IB5	0.003	-0.084	0.151	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	17.9
Pess_IPZ_Tamb_MedPchDis_IB4	0.017	-0.072	0.149	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	20.3
Pess_IPZ_Tamb_MedPchDis_IB3	0.036	-0.045	0.133	0.973	54.9	39.0	1.5	10.9	0.8135	9.63	26.5
BG_IPZTamb_MedPchDis_IB5	0.003	-0.064	0.129	0.999	13.0	0.0	0.0	0.4	0.8343	9.00	27.3
BG_IPZTamb_MedPchDis_IB4	0.017	-0.047	0.121	0.993	30.3	22.7	0.2	3.1	0.8316	10.14	35.4
BG_IPZTamb_MedPchDis_IB3	0.036	-0.015	0.098	0.742	77.3	40.7	20.0	39.6	0.8579	13.35	43.7
Opt_IPZTamb_MedPchDis_IB5	0.003	-0.047	0.107	0.980	21.0	14.7	0.5	3.6	0.8267	10.45	45.6
Opt_IPZTamb_MedPchDis_IB4	0.017	-0.026	0.092	0.797	41.7	33.3	8.6	22.4	0.8635	13.37	57.9
Opt_IPZTamb_MedPchDis_IB3	0.036	0.010	0.064	0.180	101.4	28.6	83.2	46.7	0.9160	21.23	62.5
Pess_IPZTamb_MedPchDis_K60	0.003	-0.081	0.149	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	19.2
Pess_IPZTamb_MedPchDis_K90	0.003	-0.077	0.146	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	19.8
Pess_IPZTamb_MedPchDis_K120	0.003	-0.079	0.148	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	19.4
Pess_IPZTamb_MedPchDis_K200	0.003	-0.079	0.148	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	19.5
BG_IPZTamb_MedPchDis_K60	0.003	-0.065	0.130	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	27.2
BG_IPZTamb_MedPchDis_K90	0.003	-0.066	0.131	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	26.8
BG_IPZTamb_MedPchDis_K120	0.003	-0.065	0.132	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	27.7
BG_IPZTamb_MedPchDis_K200	0.003	-0.064	0.129	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	27.2
Opt_IPZTamb_MedPchDis_K60	0.003	-0.055	0.117	1.000	0.0	0.0	0.0	0.2	0.0000	0.00	36.5
Opt_IPZTamb_MedPchDis_K90	0.003	-0.056	0.119	0.999	8.0	0.0	0.0	0.3	0.6406	6.00	36.2
Opt_IPZTamb_MedPchDis_K120	0.003	-0.055	0.117	0.999	17.0	0.0	0.0	0.5	0.8426	9.00	36.8
Opt_IPZTamb_MedPchDis_K200	0.003	-0.055	0.118	0.994	7.9	2.9	0.1	0.6	0.7929	6.83	36.6
Pess_IPZ_High_poach	0.003	-0.112	0.326	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	11.2
BG_IPZ_High_poac	0.003	-0.126	0.334	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	12.5
Opt_IPZ_High_poach	0.003	-0.133	0.347	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	13.2
Metapopulation scenarios involving 2 and 3 sites											
MP_zeroPoach_Dis_BBS	0.003	-0.010	0.075	0.209	22.6	19.4	18.1	19.4	0.8113	9.53	77.7
MP_zeroPoach_Dis_GL	0.003	-0.007	0.062	0.070	37.9	24.3	35.3	25.2	0.8735	14.97	84.8
MP_zeroPoach_Dis_WK	0.003	-0.009	0.072	0.144	18.8	10.5	16.2	11.6	0.8172	9.28	83.1
MP_zeroPoach_Dis_Meta	0.003	-0.006	0.039	0.004	69.9	34.0	69.6	34.2	0.9356	30.12	96.5
MP_LowPoach_Dis_BBS	0.003	-0.031	0.102	0.894	17.4	16.1	2.0	7.5	0.7950	8.44	57.6
MP_LowPoach_Dis_GL	0.003	-0.024	0.085	0.617	22.1	17.3	8.7	15.1	0.8361	11.15	71.1
MP_LowPoach_Dis_WK	0.003	-0.029	0.097	0.848	12.6	8.6	2.1	5.6	0.7748	7.36	64.8
MP_LowPoach_Dis_Meta	0.003	-0.028	0.073	0.466	23.2	18.1	12.7	17.4	0.8444	12.27	82.8
MP_MedPoach_Dis_BBS	0.003	-0.078	0.138	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	25.5
MP_MedPoach_Dis_GL	0.003	-0.057	0.115	0.996	24.8	11.8	0.1	1.7	0.8554	12.75	40.8
MP_MedPoach_Dis_WK	0.003	-0.066	0.125	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	32.8
MP_MedPoach_Dis_Meta	0.003	-0.071	0.106	0.996	24.8	11.8	0.1	1.7	0.8554	12.75	46.4
MP_HighPoach_Dis_BBS	0.003	-0.134	0.353	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	13.6
MP_HighPoach_Dis_GL	0.003	-0.139	0.350	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	14.8

Scenario	det-r	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	AlleleN	MeanTE
MP_HighPoach_Dis_WK	0.003	-0.138	0.347	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	14.6
MP_HighPoach_Dis_Meta	0.003	-0.156	0.372	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	18.7
MP_zeroPoach_Dis_move_BBS	0.003	-0.003	0.070	0.033	32.6	24.0	31.7	24.2	0.9246	23.23	77.7
MP_zeroPoach_Dis_move_GL	0.003	-0.003	0.058	0.014	46.6	25.4	46.0	25.8	0.9380	27.88	80.7
MP_zeroPoach_Dis_move_WK	0.003	-0.003	0.067	0.037	25.4	11.5	24.5	12.1	0.9255	21.52	81.9
MP_zeroPoach_Dis_move_Meta	0.003	-0.001	0.036	0.001	102.3	40.2	102.2	40.3	0.9519	36.53	91.0
MP_LowPoach_Dis_Move_BBS	0.003	-0.009	0.148	0.559	10.3	12.5	5.1	9.5	0.8022	9.54	60.4
MP_LowPoach_Dis_Move_GL	0.003	-0.023	0.087	0.619	25.5	20.2	99.7	17.5	0.8896	17.08	74.8
MP_LowPoach_Dis_Move_WK	0.003	-0.026	0.098	0.750	15.0	10.5	3.9	8.3	0.8700	13.29	69.1
MP_LowPoach_Dis_Move_Meta	0.003	-0.025	0.071	0.416	31.7	26.3	18.8	25.3	0.8868	17.69	85.1
MP_MedPoach_Dis_Move_BBS	0.003	-0.045	0.206	1.000	0.0	0.0	0.0	0.1	0.0000	0.00	25.6
MP_MedPoach_Dis_Move_GL	0.003	-0.067	0.127	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	36.5
MP_MedPoach_Dis_Move_WK	0.003	-0.070	0.134	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	32.2
MP_MedPoach_Dis_Move_Meta	0.003	-0.079	0.113	1.000	0.0	0.0	0.0	0.1	0.0000	0.00	43.2
MP_HighPoach_Dis_move_BBS	0.003	-0.113	0.357	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	12.8
MP_HighPoach_Dis_move_GL	0.003	-0.146	0.352	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	13.8
MP_HighPoach_Dis_move_WK	0.003	-0.141	0.348	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	13.9
MP_HighPoach_Dis_move_Meta	0.003	-0.156	0.370	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	18.7
MP_zeroPoach_dis_2sites_Hypo1	0.003	-0.005	0.055	0.030	53.7	33.2	52.1	33.9	0.9045	19.73	89.3
MP_zeroPoach_dis_2sites_Hypo2	0.003	-0.005	0.055	0.024	54.1	34.1	52.8	34.6	0.9032	19.69	85.2
MP_zeroPoach_dis_2sites_Meta	0.003	-0.003	0.037	0.000	104.9	49.0	104.9	49.0	0.9511	38.50	0.0
MP_LowPoach_Dis_2sites_Hypo1	0.003	-0.018	0.074	0.376	31.8	26.9	20.1	26.1	0.8699	14.58	77.1
MP_LowPoach_Dis_2sites_Hypo2	0.003	-0.018	0.074	0.384	32.9	26.9	20.5	26.3	0.8722	14.75	78.0
MP_LowPoach_Dis_2sites_Meta	0.003	-0.016	0.056	0.129	46.4	36.2	40.6	37.0	0.9014	21.43	87.0
MP_MedPoach_Dis_2sites_Hypo1	0.003	-0.048	0.104	0.978	21.9	14.9	0.5	3.9	0.8686	13.23	51.5
MP_MedPoach_Dis_2sites_Hypo2	0.003	-0.048	0.104	0.970	23.5	21.3	0.7	5.4	0.8657	12.80	51.3
MP_MedPoach_Dis_2sites_Meta	0.003	-0.051	0.095	0.948	22.9	18.7	1.2	6.6	0.8675	13.04	62.0
MP_HighPoach_Dis_2sites_Hypo1	0.003	-0.140	0.334	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	16.8
MP_HighPoach_Dis_2sites_Hypo2	0.003	-0.139	0.333	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	16.8
MP_HighPoach_Dis_2sites_Meta	0.003	-0.151	0.350	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	20.2
MP_zeroPoach_Dis_move_2sites_Hypo1	0.003	-0.005	0.071	0.043	28.8	22.0	27.7	22.1	0.9023	18.57	77.1
MP_zeroPoach_Dis_move_2sites_Hypo2	0.003	-0.004	0.059	0.015	43.2	24.9	42.6	25.2	0.9171	22.06	84.0
MP_zeroPoach_Dis_move_2sites_Meta	0.003	-0.003	0.044	0.008	70.8	36.9	70.3	37.2	0.9280	25.59	90.5
MP_LowPoach_Dis_Move_2sites_Hypo1	0.003	-0.014	0.143	0.669	10.7	13.6	4.0	9.2	0.7980	8.70	59.2
MP_LowPoach_Dis_Move_2sites_Hypo2	0.003	-0.024	0.088	0.650	26.4	21.3	9.4	17.8	0.8784	15.05	71.8
MP_LowPoach_Dis_Move_2sites_Meta	0.003	-0.026	0.078	0.555	29.5	25.1	13.3	22.1	0.8725	14.97	77.3
MP_HighPoach_Dis_move_2sites_Hypo1	0.003	-0.130	0.338	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	16.4
MP_HighPoach_Dis_move_2sites_Hypo2	0.003	-0.147	0.336	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	15.8
MP_HighPoach_Dis_move_2sites_Meta	0.003	-0.153	0.353	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	20.3
MP_MedPoach_Dis_Move_2sites_Hypo1	0.003	-0.050	0.196	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	26.0
MP_MedPoach_Dis_Move_2sites_Hypo2	0.003	-0.068	0.127	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	36.0
MP_MedPoach_Dis_Move_2sites_Meta	0.003	-0.076	0.119	1.000	0.0	0.0	0.0	0.0	0.0000	0.00	39.9
Captive scenarios – comparison with wild at 2 carrying capacities											
Captive_IBI33_K300	0.049	0.026	0.072	0.100	189.3	101.1	170.4	111.4	0.7902	7.27	38.2

Scenario	det-r	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	AlleleN	MeanTE
SRhino_Base_Captive_K300	0.031	0.009	0.088	0.312	55.2	48.2	38.1	47.4	0.7292	5.86	47.6
SRhino_Base_rzero_K300	0.008	0.000	0.049	0.019	66.1	43.7	64.8	44.2	0.9048	19.76	80.2
SRhino_Base_r3	0.031	0.026	0.035	0.000	295.8	14.3	295.8	14.3	0.9611	44.30	0.0
Captive_IBI33_K10	0.049	0.017	0.109	0.445	7.9	2.1	4.7	4.0	0.4938	2.83	58.0
SRhino_Base_rzeroK10	0.008	0.021	0.122	0.982	4.0	1.9	0.1	0.6	0.5384	2.89	40.9
SRhino_Base_r3_K10	0.031	0.006	0.115	0.846	5.4	2.3	1.0	2.1	0.4946	2.76	53.6
Captive scenarios with harvest for translocation and supplementation to manage inbreeding											
Captive_Harv_K10	0.049	0.010	0.101	0.511	8.2	2.0	4.5	4.2	0.4822	2.77	53.6
Captive_Harv_K15	0.049	0.016	0.085	0.195	13.3	2.4	11.0	5.3	0.5765	3.66	54.8
Captive_Harv_K20	0.049	0.019	0.078	0.121	18.5	2.7	16.4	6.3	0.6348	4.31	45.1
Captive_Harv_K30	0.049	0.021	0.074	0.101	28.2	4.3	25.4	9.4	0.6765	5.07	39.5
Captive_Harv_K40	0.049	0.022	0.073	0.135	37.2	7.3	32.2	14.4	0.6931	5.54	37.7
Captive_Harv_K50	0.049	0.024	0.071	0.107	46.2	9.3	41.3	16.7	0.7232	5.97	39.4
Captive_Harv_K10_NoInb	0.049	0.019	0.101	0.503	9.0	1.6	5.1	4.4	0.4318	2.57	50.8
Captive_Harv_K15_noinb	0.049	0.025	0.085	0.187	14.1	1.6	11.9	5.1	0.5581	3.51	55.5
Captive_Harv_K20_NoInb	0.049	0.019	0.078	0.137	18.4	2.8	16.1	6.6	0.6389	4.39	48.1
Captive_Harv_K30_NoInb	0.049	0.031	0.072	0.063	29.3	2.3	27.4	7.4	0.6668	4.95	26.6
Captive_Harv_K40_NoInb	0.049	0.033	0.070	0.057	38.9	3.3	36.7	9.6	0.6867	5.39	28.9
Captive_Harv_K50_NoInb	0.049	0.034	0.067	0.053	49.1	3.1	46.5	11.4	0.7126	5.86	24.3
Captive_Harv_K10_Add2	0.049	0.038	0.112	0.081	9.1	1.3	9.0	1.5	0.8194	8.01	53.8
Captive_Harv_K15_Add2	0.049	0.037	0.089	0.016	14.2	1.4	14.2	1.5	0.8444	10.15	60.3
Captive_Harv_K20_Add2	0.049	0.037	0.078	0.005	19.3	1.5	19.3	1.5	0.8533	11.61	56.9
Captive_Harv_K30_Add2	0.049	0.038	0.067	0.000	29.4	1.6	29.4	1.6	0.8682	14.00	69.0
Captive_Harv_K40_Add2	0.049	0.039	0.063	0.000	39.5	1.8	39.5	1.8	0.8804	16.13	8.0
Captive_Harv_K50_Add2	0.049	0.039	0.061	0.000	49.4	1.9	49.4	1.9	0.8845	17.56	9.0

References

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

Frankham, R., Ballou, J., & Briscoe, D. (2002) *Introduction to Conservation Genetics*. Cambridge Univ. Press.

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 Bulletin*, 48, 191-203.

Lacy, R.C., & Pollack, J.C. (2014) VORTEX: A stochastic simulation of the extinction process. Version 10.0. Chicago Zool. Soc., Brookfield, Illinois. U.S.A.

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

Oberwemmer, F. (2014) International Studbook for Sumatran Rhinos, *Dicerorhinos sumatrensis*. Unpublished, Leipzig Zoo.

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

Putnam, A. (2013) Captive pop anal unpublished workshop report)

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 I: *Vortex* Input Parameters

The Vortex Simulation Model

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

The software used in these analyses is the simulation program *VORTEX* (v10.0.7.9) (Lacy & Pollack, 2014). *VORTEX* is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events, on small wild or captive populations. *VORTEX* models population dynamics as discrete, sequential events that occur according to defined probabilities. The program begins by either creating individuals to form the starting population, or by importing individuals from a studbook database. It then steps through life cycle events (e.g., births, deaths, dispersal, catastrophic events), for each individual and typically on an annual basis. Events such as breeding success, litter size, sex at birth, and survival are determined based upon designated probabilities that incorporate both demographic stochasticity and annual environmental variation. Consequently, each run (iteration) of the model gives a different result. By running the model hundreds of times, it is possible to examine the probable outcome and range of possibilities. For a more detailed explanation of *VORTEX* and its use in population viability analysis, see Lacy (1993, 2000) and Miller and Lacy (2005).

Model Input Parameters

Few data are available on the biology of wild Sumatran rhinos and only a small number of Sumatran rhinos have ever been held in captivity. As so few species-specific data were available to inform the development of the models, parameters were been based on:

- limited data from previous population viability analyses (Soemarna et al., 1994; Ellis et al, 2011; Putnam, unpubl.);
- real data on other rhino species, mainly from captive populations of Asian one-horned rhinoceros, *Rhinoceros unicornis*;
- estimates from experts elicited during the Sumatran Rhino Crisis Summit (held at Singapore Zoo in 2013) and Javan and Sumatran rhino workshops held at Taman Safari, Indonesia, in 2015.

Settings

All scenarios were simulated 1000 times with results averaged across all iterations. Each model projection extended out 100 years (roughly 5 rhino generations), with demographic and genetic results summarised at the end of each year.

Inbreeding depression

VORTEX allows the detrimental effects of inbreeding to be modelled through a reduction in first year survival. No data are currently available that would allow an assessment of the susceptibility of Sumatran rhino populations to inbreeding. Default VORTEX settings of 6.26 LEs for wild populations and 3.14 LEs for captive populations were applied, based on analyses by O'Grady et al. (2006) and Ralls & Ballou (1988) respectively. As a result, inbreeding has a less severe impact in the captive models, emulate the less stressful conditions.

50% of the total genetic load is derived from lethal alleles (the default values provided by VORTEX).

Breeding system

The breeding system was specified as polygynous, with each male being able to breed with multiple females in 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. Captive Sumatran rhinos have been recorded to breed for the first time at 6 years (females) and 8 years (males). In the models, females may breed for the first time at 6 years, males for the first time at 10 years to allow for the expectation that only larger and more experienced males would be likely to breed successfully in the wild.

Maximum age of reproduction and longevity

Female rhinos are known to be capable of breeding into their thirties but there are few examples of this. Maximum age of breeding is set to 35 in the models and longevity at 40, for both sexes.

Offspring production

Females produce only one calf per parturition. Though it has been suggested that a slight male bias in sex-ratio at birth is likely for a species of this type, sex-ratio at birth is set to 50:50 in the models.

Percent females breeding

The shortest inter-birth interval for a female Sumatran rhino (producing surviving offspring) is approximately 3 years. This was considered optimistic for remaining wild rhinos and an inter-birth interval of 4 years was considered more realistic. Female breeding rates were set at 25%, reduced to 20% in some models to manipulate annual growth rates to zero, and increased to 33% in some of the captive models to represent the possibilities of active reproduction manipulation.

Percent males in breeding pool

100% of males were considered available for breeding in the captive models, 80% in the wild models representing likely male-male competition.

Mortality rates

Few data were available on which to base estimates of this. Representative first year mortality rates in captivity for other species (approximately 15%) were increased to allow for the increased stresses of the wild, to provide estimated first year mortality rates of 20% for both sexes, increasing to 23% in some models to create “zero growth” scenarios. Beyond the first year, mortality rates were set to 3% (rising to 5% in the zero growth model) up to age 30, after which rates were increased to 10% using a function:

```
(3+((A>30)*7)))
```

Number of populations, starting population size and carrying capacity

A range of starting populations were applied in the models to illustrate different effects. Estimates generated by working groups at the 2015 PVA workshop were used for wild sites and for the sub-populations within them (see below). For the captive models the starting population was imported from a studbook file generated using pedigree, age and gender information from the International Studbook (Oberwemmer, 2014).

Genetic management and breeding pair selection

No genetic management was included in the wild models.

Transfer rates

Some of the 3-site metapopulation models involved inter-site exchanges. These involved the movement of 2 individuals from each site to one other site, so that each site both exported and imported 2 adult rhinos, each year. This was done using the Dispersal facility, specifying a number of animals rather than a percentage.

Catastrophes

Catastrophes are modelled as extreme mortality or reproduction events occurring in a single year. Disease was included as a catastrophe in some of the models. Frequency of occurrence was varied, and when it occurred it resulted in a 10% drop in survival and a 5% drop in reproduction.

Harvesting

Poaching was modelled using the Harvest facility. This facility standardly allows the user to specify the period over which harvesting occurs and the frequency of occurrence. The variation in number harvested was addressed by a random number generator drawing from a distribution with a specified mean and standard deviation as follows:

<u>Low level poaching (0-2 rhinos every 2 years):</u>
Number of adult male and female rhinos harvested = MAX(0+(1*NRAND);0)

<u>Medium level poaching (0-4 rhinos every year):</u>
Number of adult male and female rhinos harvested = MAX(0+(1.5*NRAND);0)

<u>High level poaching (4-8 rhinos poached over 1-2 years, occurring every 4-8 years):</u>
This involved setting Global State Variables and some additional steps as follows:

- Set GS1 =RAND (for both init & trans functions);
- Set GS2 init funct = 4+(GS1>0.1)+(GS1>0.3)+(GS1>0.7)+(GS1>0.9);
- Set GS2 trans funct = IF(Y>GS2; GS2+4+(GS1>0.1)+(GS1>0.3)+(GS1>0.7)+(GS1>0.9); GS2);
- Set GS3 = IF(Y>GS3;GS2+(RAND>0.8);GS3) (for both init & trans functions);
- Set Optional criteria for harvest = (Y=GS2)OR(Y=GS3)
- Set Adult harvest = 20+(5*NRAND)

The Harvesting facility was also used to estimate the allowable harvesting rate from the captive population. In any year in which captive carrying capacity was exceeded, VORTEX calculated the number of amount of surplus individuals and harvested that number from the adult population (half half from the males, half from the females). The actual number harvested in this way was tracked using the Special Option “Produce a file with the census for the first X iterations”, which tracks harvest amongst other values.

Baseline model values are provided in the table below.

Vortex Parameter	2015 Baseline 1: 2-3% annual growth	2015 Baseline 2: 0% annual growth	2015 Baseline 2: captive population
Number of populations	1	1	1
Inbreeding depression (included as lethal equivalents)	6.29	6.29	3.14
Concordance of environmental variation (EV) and reproduction	No	No	No
Breeding system	Polygynous	Polygynous	Polygynous
Age of first reproduction (♂ / ♀)	10 and 6 years	10 and 6 years	10 and 6 years
Maximum age	40	40	40
Maximum age of reproduction	35	35	35
Annual % adult females breeding	25	20	25
Density dependent reproduction?	No	No	No
% males in breeding pool	80	80	80
Litter size	1	1	1
Offspring sex ratio	0.5	0.5	0.5
% annual mortality (♀) (EV)			
0-1 years	20% (4)	23% (4)	20% (4)
1-6 years	3% (2)	5% (1)	3% (2)
7+ years	(3+((A>30)*7))% (2)	(5+((A>30)*7))% (1)	(3+((A>30)*7))% (2)
% annual mortality (♂) (EV)			
0-1 years	20% (4)	23% (4)	20% (4)
1-10 years	3% (2)	5% (1)	3% (2)
11+ years	(3+((A>30)*7))% (2)	(5+((A>30)*7))% (1)	(3+((A>30)*7))% (2)
Initial population size	50	50	9 (read in from SB file)
Carrying capacity (K)	300	300	300

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