Debate forum

Preventing the extinction of the Sumatran rhinoceros

Abdul Hamid Ahmad, **Junaidi Payne** and **Zainal Zahari Zainuddin**

Borneo Rhino Alliance, c/o Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah

Corresponding author: Junaidi Payne, email: *sabahpayne@gmail.com*

The decline of the Sumatran rhinoceros in the 20th century

Sumatran rhino (SR), *Dicerorhinus sumatrensis*, represents one the oldest surviving mammal genera. Due to its role in traditional Chinese medicines, the horn of SR has been sought for well over a millennium and for many years the price of SR horn by weight rivalled that of gold. Extensive hunting lead to a precipitous decline in distribution and numbers of SR, particularly during the first decades of the twentieth century (van Strien, 1975) and it seems little short of a miracle that the species is not already extinct. By the mid twentieth century, the species was depleted from its former range and in danger of extinction in Malaya and Borneo (Hubback, 1939; Metcalf, 1961; Medway, 1977; Rookmaaker, 1977), and elsewhere on mainland Asia (Harper, 1945). Flynn and Abdullah (1984) suggested 52-75 SR roamed Peninsular Malaysia in the early 1980s, including 20-25 individuals in the Endau-Rompin area, while Davies and Payne (1982) estimated 15-30 SRs in Sabah. By 1981, the only clear evidence of periodic breeding in wild SR in Malaysia was in Endau-Rompin and the Tabin area of eastern Sabah. At that time, the species was disappearing rapidly from the 20 or more locations where it had been present just a few decades earlier (Payne, 1990). Zainal Zahari (1995) found evidence of only five SRs, all adults, in Endau-Rompin by 1995, showing that published estimates of SR numbers were notoriously unreliable, and that actual numbers had declined by half over the preceding decade. The 1995–1998 Global Environment Facility-UNDP Sumatran Rhinoceros Conservation Strategy project saw SR numbers declining still further, but inflated numbers kept appearing in public domain, largely due to some proponents' disbelief that two decades of effort had failed. Zainal Zahari et al. (2001) plotted the disastrous decline of large mammals in Peninsular Malaysia from 1975-99.

The 1st Sumatran Rhino Crisis Summit

In October 1984, twenty persons convened on SR in Singapore by IUCN and, in the absence of reliable information on the population density of SR or on the species' breeding biology, representatives from governments, zoos and wildlife institutions made plans to prevent the species' extinction. The participants called for enhanced protection of wild SR populations, awareness, and development of a global captive breeding population drawn from SR in areas that were to be converted to plantations. Unfortunately, by 2013 the numbers of wild SR remained unknown despite evidence of a precipitous decline from several hundred individuals in 1984 to less than 100 in 2013.

The 2nd Sumatran Rhino Crisis Summit

The 2nd Sumatran Rhino Crisis Summit (SRCS) was also held in Singapore, from 31 March – 4 April 2013. About 100 people from governmental institutions, and non-governmental organisations (NGOs), together with Asian and African rhino experts, passionate individuals and people who have been involved in succeeding or failing to prevent the extinction of other species in recent decades participated. Originally conceived in Sabah as a NGO-led event, SRCS was eventually convened by IUCN, hosted by Wildlife Reserves Singapore (WRS).

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Figure 1. The Sumatran rhinoceros, *Dicerorhinus sumatrensis*, is on the edge of extinction. Conservation breeding actions, using all the knowledge about reproduction as well as international collaboration, is needed to prevent this charismatic species from being the next large mammal to go extinct in Asia. ©Carl Traeholt.

SRCS covered far more detail than the 1984 meeting, and discussions were far more nuanced, but the gist of the conclusions was similar (JP, pers. obs.). The SR is on the edge of extinction, and without immediate and committed conservation intervention drawing on the experience and resouces of Governments, scientists, captive and natural facilities, the species will almost certainly be extinct within the near future.

Simulations run in conjunction with SRCS found that female inter-birth interval was the single most important predictor of population performance. To have good chance of surviving through protection there is a need for a minimum 30 individuals with an inter-birth interval of three years or less. The future of populations numbering less than 30 individuals is bleak even if healthy and completely protected. Using a more realistic average inter-birth interval of 7 years, a starting population of 50 SR has a negative growth rate of about -3% per year. This effectively means that, without active intervention, all possible known wild and captive populations are in an extinction vortex and not sufficiently abundant to increase populations in isolation of each other. To reduce the current captive population's extinction probability below 10%, approximately 16 adult wild-caught rhinoceros need to be transferred into captivity and managed with an interbirth interval of three years.

The main specific actions agreed upon at SRCS were for Indonesia and Malaysia to collaborate, and to obtain critical ecological information about wild SRs, using ground observations, camera traps and faecal DNA analyses. Despite pledged commitment and support from all sides, some important, hard questions were not resolved at SRCS.

The hard reality

Between 1984-2013 forty-four SR have been captured from the wild, with only four captive births, all descendants from the same pair in Cincinnati Zoo. Disastrously, of the forty-four, 40 had died by early 2014. By 2014, there were only 9 SR in captivity: one mature male (born in Cincinnati Zoo, 2001), three fertile females and one male infant (born 2012) in the Sumatran Rhino Sanctuary, Way Kambas National Park, Sumatra, Indonesia; a sister and brother, both born and present in Cincinnati Zoo; a fertile female with endometrial cysts, and an aging male in the Borneo Rhino Sanctuary temporary facilities in Tabin Wildlife Reserve, Sabah, Malaysia. Despite a few positive results the conservation breeding effort has been an outright failure, and much more needs to be done before success can be achieved.

Unfortunately, after 1970 the dominating conservation approach has been to save highly endangered species in the wild, rather than to bring them into fenced, managed conditions. This was already apparent at the IUCN SR meeting in Singapore in 1984, where the majority of the participants expressed that protection of wild Sumatran rhinos and their habitats should be the prime means to save the species, with captive breeding as a supplement (JP, pers. obs.). In his 1995 polemic, Rabinowitz (1995) took the view that precious funds had been wasted on the captive breeding efforts, which should have been spent instead on guarding wild rhinos. Unfortunately,

his as well as many others' reasoning, did not address the likely impacts of stochastic variables on small isolated wild populations (e.g. the Allee effect), and made no analysis of the particular faults and problems that were associated with the captive breeding attempts 1984-95. Today, it is well-known that the vulnerability of small wild populations to stochastic variables is critical and the catholic approach to captive breeding will likely send the respective species into an irreversible extinction vortex.

Sumatran rhinoceros in Malaysia

There is finally a realisation in Malaysia that SR is most likely extinct in Peninsular Malaysia, and on the verge of extinction in Sabah. Malaysia muddled through with SR in the past fifty years, recycling fabricated population estimates and refraining from making necessary conservation decisions. Now, government and NGOs alike implicitly agree that the sole imperative is to produce Sumatran rhino embryos. This can only be done by bringing every rhino into closely managed facilities, and making maximum use of their gametes. Having these rhinos and gametes as part of a globally managed meta-population is essential, and attempts at natural breeding and artificial insemination must continue as long as either is possible. In the absence of agreement to share rhinos and gametes between nations and facilities, current scope in Malaysia is extremely limited. Thus, a key element of effort commencing 2014 is the cryo-preservation of gametes and cells that might be used in the future to restore the species after its extinction in Malaysia.

The lesson from Malaysia is that the over-riding priority should have been to increase the number of SR pregnancies per year rather than to hope that the mortality rate of wild SR through poaching could be reduced. Protecting wild SRs may be an over-ambitious option and captive breeding may have a greater chance of success than prevailing wisdom admits.

The 1984-95 Sumatran rhino captures and breeding programme

From 1984 – 1995, 22 SR were captured in Malaysia (Table 1) with the intention to build a captive breeding programme. When SR captures commenced in the 1980s, nothing was known of SR reproductive biology other than basic anatomy. The only captive SR birth during the 1984-95 period was of Minah, from a mother who was pregnant when captured (Table 1).

An analysis of the fate of these SRs reveals several kinds of failures which should not have been allowed to occur with such a precious, critically-endangered species. For a start, although the possibility existed to exchange individuals between Peninsular Malaysia and Sabah for captive breeding, this was never seriously discussed because of a belief that the Peninsular Malaysian and Borneo rhinos are different sub-species. This notion arose from a paper by Groves (1965), who examined the skulls of thirteen Dicerorhinus rhinos from Borneo, Sumatra, Malaya and Burma, and concluded that the Borneo form is "markedly smaller" with a forward-sloping occiput (back end of skull), and therefore ranked as a distinct sub-species (*D. r. harrissoni*), with *D. r. sumatrensis* regarded as a single form occurring in Sumatra and Peninsular Malaysia. Despite the small sample size and subjective nature of the judgement, this publication served as a basic constraint to rational discussion. Amato et al. (1995) recommended mixing the "sub-species", a recommendation later endorsed by Goossens et al. (2013), which implicitly questions the validity of the sub-species separation. Despite acceptance by Groves (1965) that the Peninsular Malaysia and Sumatra Dicerorhinus are the same sub-species, there was only one attempt at exchanging rhinos. Peninsular Malaysia provided a female (Dusun, who had been captured in 1984, healthy and with no obvious reproductive pathology) to Indonesia in 1987, while a male (Napangga) captured on 15 June 1986 in Sumatra was sent to Peninsular Malaysia, which at that time lacked a captive male. However, Napangga was suffering from severe and chronic snare wounds in his front left leg, which had resulted in a fractured meta-carpus and severe exostosis of several bones, rendering it almost impossible for him to mount a female. Dusun was kept in Rangunan Zoo, Jakarta, for 11 years, before being sent to Way Kambas in 1998, where she died without breeding in 2001.

Although there was clear knowledge well before 1980s that SR live in closed-canopy forest and that wild SRs typically wallow in clean mud for 5- 6 hours daily (Ng et al., 2001), most SR were kept in conditions of exposure

Table 1. Summary of Sumatran rhinos, *Dicerorhinus sumatrensis*, brought into captivity in Peninsular Malaysia and Sabah from 1984 to present.

Rhino name	Sex	Date of capture	Characteristics & history	Death (cause; location; date)
Peninsular Malaysia				
Jeram	F	30/04/84	Mature at capture; from oil palm near Sungai Dusun peat swamp forest in Selangor; never bred	Old age related; Melaka Zoo; 09/07/02
Erong	M	01/05/84	Caught at age about 2 months; fed full cream cow's milk from cartons; later analysis of captive SR showed that SR milk is very low in fat and high in protein	Feeding unsuitable milk ; Melaka Zoo; 01/06/84
Melintang	F	18/04/85	Mature at capture; Perak State; sent as gift from King of Malaysia to King of Thailand, July 1986	Dislocation of neck & suffocation between bars of inappropriate fence; Dusit Zoo, Bangkok; 28/11/86
Rima	F	15/12/85	Pregnant at capture; Johor; retained in Melaka Zoo & Sungai Dusun	Likely mucoid *E.coli* infection (previously reported in public domain as tetanus); Sg. Dusun; 12/04/03
Sri Delima	F	01/07/87	Mature at capture; Selangor; retained in Melaka Zoo & Sungai Dusun	Salmonellosis (Salmonella blockley); Melaka; 15/12/89
Dusun	F	09/09/86	Mature at capture; sent to Jakarta 25/05/87 in exchange for male	Old age related; Way Kambas; 07/02/01
Panjang	F	25/07/87	Mature at capture; Selangor; retained in Melaka Zoo & Sungai Dusun	Bacterial infection; Sg. Dusun; 09/11/03
Minah	F		Captive born to Rima in Melaka Zoo on 23/05/87; a progesterone implant was inadvertently placed into her bladder by a Universiti Pertanian Malaysia specialist, an error inadvertently attributed in public domain to ZZZ	Bacterial infection; Sg. Dusun; 16/11/03
Julia	F	06/07/86	Mature at capture; Selangor; retained in Melaka Zoo	Uncertain; Melaka Zoo; 23/09/88
Mas Merah	F	26/08/87	Mature at capture; Selangor; retained in Melaka Zoo & Sungai Dusun	Bacterial infection; Sg. Dusun; 17/11/03
Shah	M	01/03/88	Estimated age at capture 2.5 years (weight 446 kg); Selangor; retained in Melaka Zoo & Sungai Dusun	Mucoid *E. coli* infection (previously reported in public domain as colitis or emphysema); Sg. Dusun; 19/01/02
Seputih	F	11/07/88	Mature at capture; Pahang; retained in Melaka Zoo & Sungai Dusun	Bacterial infection; (previously reported in public domain as intestinal torsion); Sg. Dusun; 28/10/03
Ara	M	24/08/94	Mature at capture ; retained in Melaka Zoo & Sungai Dusun	Bacterial infection; Sg. Dusun; 08/11//03
Sabah				
Linbar	M	28/03/87	Mature at capture	Internal injury & respiratory failure at trap site; lower Segama; 28/03/87
Tenegang	M	14/07/87	Mature at capture	Hindgut obstruction was cited, without details; Sepilok; 22/04/92
Lokan	M	24/05/88	Mature at capture	In pit trap; 25/05/88
Lun Parai	F	22/04/89	Juvenile at capture; first mated 28/10/95 but no pregnancy; retained at Sepilok & Tabin	Uncertain ; Sepilok; 23/08/00
Tekala	M	05/05/91	Mature at capture; retained at Sepilok	Reported as tetanus; Sepilok; 08/05/95
Sidom	M	27/08/92	Mature at capture; mated unsuccessfully with Lun Parai and Gelogob at Sepilok	Uncertain; Sepilok; 20/01/97
Bulud	M	07/07/93	Mature at capture; escaped through electric fence into Tabin Wildlife Reserve, 30/11/93	Unknown (but seen in June 1995, 30 km from escape site, identified by radio-collar around neck)
Tanjung	M	20/07/93	Mature at capture; retained at Sepilok	Falling tree branch; Sepilok; August/06
Malbumi	M	22/11/95	Mature at capture; retained at Sepilok	Unknown; Sepilok; 04/12/97
Gelogob	F	17/06/94	Mature at capture; mated 26/10/95 but no pregnancy; retained in Sepilok, Tabin & Lok Kawi	Died 11/01/2014
Kertam (Tam)	M	15/08/08	Mature at capture; front right leg with snare wound; coaxed into crate in in oil palm at Kretam. Retained in Tabin.	Alive
Puntong	F	18/12/11	Pit trap in Tabin; mature on capture; front left foot absent, clearly amputated in early infancy; significant reproductive tract pathology. Retained at Tabin.	Alive

to sunlight and in some cases without access to clean mud wallows. SR skin condition declines drastically when this species is provided only with water or watery mud in which to wallow, leading to poor condition and stress. Frequent sunlit conditions have been linked to partial and complete blindness in some captive SRs (Kretzschmar et al., 2009). In summary, many SR were kept during 1984-95 in conditions which facilitated poor health and stress. Other mistakes made in the 1980s included feeding unsuitable milk to an infant SR and keeping a SR in an enclosure which allowed the rhino to entrap its head between the bars, and asphyxiate.

Most egregious of all, basic hygiene was generally poor, with at least some SRs kept for long periods in facilities that lacked basic hygiene protocols and biosecurity measures, and lacked experienced veterinary care so that identification and treatment of disease came too late or not at all. Prior to the development of the Sungai Dusun Rhino Conservation Centre (SDRCC) in Peninsular Malaysia, SRs were maintained at Melaka Zoo, where treated piped water was installed only after the deaths of Sri Delima and Julia (Table 1). Aidi et al. (2004) reported that the SDRCC rhinos died as a result of trypanosomiasis, supposedly originating from buffalo on private land nearby. Monthly monitoring of blood for parasites and blood parameters had been done for all captive SR for almost a decade prior to the deaths of six SR in SDRCC in year 2003, however, and no trypanosomes had been detected. Blood was taken from the buffaloes living near to the SDRCC facility after the six SR deaths in 2003, and inoculated into mice, but no trypanosome infection was detected. In only two of the seven SR that died at SDRCC were trypanosomes detected, while abundant pure bacterial growth was found post-mortem in the vital organs, mucoid *Escherichia coli* in five animals and *Klebsiella pneumoniae* in four animals. The death of Shah in January 2002 from mucoid *E.coli* should have prompted the facility to be on strict alert. Sensitivity tests were done in 2002 to determine the most effective treatment. Gentamycin was found to be the only effective treatment and, although it was available at SDRCC during the period of the final six SR deaths, it was not used. Seven years later, between 17-29 September 2010, at the same facility, seven Malayan tapirs died from mucoid *E.coli*, and only one of the tapirs showed trypanosomes in the blood. Our opinion is that trypanosomes might have infected SR and tapirs at any time at Sungai Dusun, and that natural resistance effectively supressed their growth until the advent of poor health and compromised immune response resulting from chronic mucoid *E. coli* and *Klebsiella* infection. The conclusion that trypanosomes were the cause of the SDRCC deaths may have been reached erroneously, in order to allow parties involved to avoid responsibility for chronic poor hygiene in the facilities.

Other SR facilities also had issues with hygiene and treatment. In the most detailed publicly-available documentation of a SR death in captivity, Furley (1993) wrote that the female SR named Subur in Port Lympne Wild Animal Park, United Kingdom, was diagnosed as having "died from acute bacterial toxaemia caused by *Klebsiella pneumoniae* in an environment subsequently found to be heavily contaminated with this organism" as well as with *E. coli.* High quality management, husbandry and veterinary care is essential at all times wherever SRs are kept in fenced facilities.

Post 1995 SR captive breeding

It was only in the mid 1990s that the key elements of SR reproductive behaviour had become clearer (Zainal Zahari et al., 1990, 2005; Bosi, 1996). But by the end of 1995, 4 captive SRs had died in Indonesia, 5 in Peninsular Malaysia, 4 in Sabah, and 6 in US and British zoos (Christman, 2010), and the captive breeding programme had become less appealing to governments, donor and commentators. The Sumatra-caught SRs Emi and Ipuh were not only alive, however, but fertile and compatible, and received excellent care at Cincinnati Zoo, resulting in live SR births in 2001, 2004 and 2007. Since then, attempts and advances continue to be made in assisted reproductive technologies for rhinos. Examples include the cryo-preservation of oocytes by vitrification (Saragusty and Atav, 2011), successful artificial insemination and subsequent live births of white, *Ceratotherium simum*, and Indian rhinos, *Rhinoceros unicornis*, (Hermes et al., 2009a; Anon, 2013), and in vitro fertilization (Hermes et al., 2009b; Stoops et al., 2011).

Major reasons for the 1984-95 failures

Allee effect and the Sumatran rhinoceros

The Allee effect (Allee, 1931) formally refers to a "positive correlation between population size or density

and the mean individual fitness", indicating that when a population declines to very low numbers, breeding success declines in tandem both absolutely and in terms of population size percentage change (Courchamp et al., 2008). Not everyone involved in making decisions on how to manage very small populations can digest mathematical texts on wildlife population modelling, but it should be clear that very small populations of solitary, slow-breeding species such as SR will have a very small number of annual births. The stochastic factors associated with very low numbers (e.g. difficulty in finding a mate, narrow genetic base, random skewed sex ratio, reproductive tract pathology linked to long periods without breeding) contributed to driving SR numbers lower and lower during the twentieth century, even in places with suitable habitat and zero human off-take. In small, scattered and non-contiguous "populations", it is just a matter of time before average annual death rate exceeds annual birth rate, and before the population goes extinct.

How do we know that the Allee effect is having a significant impact on prospects for survival of wild SRs? Firstly, all records of wild juvenile SR are essentially anecdotal, with no information available on actual annual increase (or decrease) in wild population size. Secondly, SR numbers have been very low for at least many decades in most if not all areas where they are still present, so inbreeding is very likely. Thirdly, a skewed sex ratio was observed during capture of SR in Malaysia from 1984-95, where the Peninsular Malaysia ratio for adult wild caught rhinos was 1:9 (male:female), while for Sabah this was the opposite, 8:1. Worse still, it was ten years after the capture of the first mature female before the first and only mature male was captured in Peninsular Malaysia (Table 1). In Sabah, all the males captured were mature or old, from the same 1,000 sq km of forest being converted to plantations. Fourthly, reproductive tract pathology is common in SR females, a phenomenon associated with lack of either breeding or carrying of foetuses to successful birth that appears to particularly afflict rhinos (Hermes et. al, 2006). More than 50% of Malaysian female SR have such a problem, and in most of these rhinos, the problem was present at time of capture (Schaffer et al., 1994, 2001). Of 9 female captive Peninsular Malaysian SRs examined, six had reproductive tract pathology, comprising of masses, cysts and tumours, observed via ultrasonography and/or post mortem.

It is manifestly unsafe to assume that wild SR populations are characterised by an average annual birth rate that matches annual death rate, are not inbred, have a non-skewed sex ratio, that females are mainly fertile, and that wild populations exceed the minimum necessary characteristics to sustain a constantly positive rate of increase. Rather, we should assume the opposite, lest we continue to field teams to protect an inherently non-viable population. The Allee effect has likely been present in all SR populations over an extended period, effectively entering SR into the extinction vortex irrespective of whatever protective measures might be put in place in the wild.

We suggest that major reasons for the failure of the 1984-95 efforts on captive breeding of SRs (with current situation in parentheses) were : (1) Insufficient knowledge of key elements of Sumatran rhino breeding biology (now largely rectified), (2) inadequate constant, high-quality veterinary care and husbandry in captive facilities (rectified at Sumatran Rhino Sanctuary in Indonesia and Borneo Rhino Sanctuary in Sabah by full-time presence of experienced veterinarians employed independently of government bureaucracy), (3) unsuitable diet in some facilities, with insufficient attention paid to the risk of iron ferritin disease (Dedi et al., 2012), (4) stress on SRs due to weaknesses in facilities design and poor visitor control (rectified at Sumatran Rhino Sanctuary in Indonesia and Borneo Rhino Sanctuary in Sabah), (5) more than 50% of all female SRs with reproductive tract pathology, making natural breeding difficult or impossible in these females (assisted reproductive technology is now better advanced, including artificial insemination attempts), (6) absence of suitable males in Peninsular Malaysia, (7) probably, some males in Sabah with low or no sperm production, (8) rhinos not shared between Peninsular Malaysia and Sabah due to fears over "different sub-species" (a fear now discounted), (9) rhinos not shared between Peninsular Malaysia and Indonesia due to loss of trust after the initial exchange, (10) rhinos not allowed to USA due to governmental decisions within Malaysia, (11) some pairings involved inexperienced or incompatible rhinos, (12) artificial insemination was never attempted due to lack of knowledge that is now available.

The hard questions

Which option is more likely to save the Sumatran rhino: protection in the wild or close management in fenced, managed facilities?

Before answering these questions it is important to draw knowledge from similar successful "rescue" interventions that have taken place for other species on the edge of extinction. In the late nineteenth century, the white, *Ceratotherium simum*, and black rhino, *Diceros bicornis*, species were saved from extinction by active management (Skinner and Chimimba, 2006). The same was done for American, *Bison bison*, and European bison, *Bison bonasus*, (Hornaday, 1887; Pucek et al., 2004), Przewalski's horse, *Equus przewalskii*, and the Arabian oryx, *Oryx leucoryx* (Ryder and Wedemeyer, 1982; Saltz, 1998; Spalton, 1999) with all four saved from extinction by zoos and private land owners. More recently, the Californian condor and black-footed ferret have been saved by captive breeding, despite the strong objections of some detractors (Nielsen, 2006; USFWS, 2008). In contrast, species which could have been brought into captivity in the 1980s but were not, and are now extinct, include the Vietnam rhino (Brook et al., 2011) and Christmas Island Pipistrelle, *Pipistrellus murrayi*, (Martin et al., 2012).

The first option is "politically" safer because no agency or individual can ultimately be held accountable for extinction, if that occurs. Also, there is no risk of adverse public comment, domestically or internationally. There is zero risk of accidents during capture. However, there are two major risks. One is that of catastrophic poaching which can wipe out many rhinos before action can be taken (this could also occur with captive rhinos). The other risk is that a positive outcome is based on the hope that birth rate and survival are adequate to surpass death rate over the coming decades, and that inbreeding does not represent a significant threat. If those two risks are under-rated, then the whole exercise of protecting wild rhinos will eventually prove to have been fruitless.

The second option can mitigate those two risks. We have three concerns that lead us to this belief. Firstly, we do not believe that anyone, even with better data on SR numbers, sex ratio and breeding signs in the remaining wild populations, can state whether those populations are of sufficient size and fecundity to assure their survival, even in the absence of poaching. Secondly, we believe that the risk of a very few catastrophic and fatal poaching events will always remain high in wild populations, and that such events would likely be the final nail in the coffin that will lead to the species' total extinction. Thirdly, we believe, based on our own personal experience, that the failure of the 1984-95 captive breeding efforts should be a hard-earned lesson for us, to inform us of what should now be done, rather than be viewed as a reason not to bring SRs into fenced facilities. However, this second option entails risks which are the opposite of the first. The agencies and individuals involved in making the decisions, and in capturing, transporting and caring for the rhinos, carry responsibility for failure. Any decision to capture Sumatran rhinos from the wild is sure to incur objections, domestically and globally, both from specialists who do not support capture, and the many people who make comments through the digital media. If the decision to capture is made and implemented, there is a whole array of risks thereafter, but with the knowledge now available, all can be mitigated.

Options for fenced, managed facilities

Four ways to manage SRs in captive conditions can be imagined (Table 2), the first two of which have already been proven to be capable of producing SRs. However, two additional options merit consideration as alternative or additional possibilities.

Sabah wasted more than a year (2008-10) in considering the model of a large enclosure under rainforest, which had been suggested in 2008 by an African rhino specialist. The reasons why such a model was found to be impractical in Sabah were: (1) not enough remaining fertile rhinos to make it worthwhile, (2) there is insufficient flat land under natural forest remaining, (3) approximate cost of the perimeter fence and motorbike track for the provisionally agreed facility was about US$10 million and (4) the alignment and maintenance of fencing under prevailing conditions of slopes, high rainfall, branch falls and erosion would render the concept impractical. It is vital to stress that a perimeter fence consisting merely of electrified wire is not suitable for the conditions that prevail in Malaysia and Indonesia. Not only will the hot wire be breached naturally and frequently by tree and branch falls and

erosion, but years of experience show that at least some wild elephants as well as rhinos may barge through the wire or push trees down on to it. The only practical way in which the large enclosure under rainforest model could work will be to select a flat area, where fence alignment, construction and maintenance is not unduly complex, and to combine the hot wire with a physical barrier, such as that already used in Sumatran Rhino Sanctuary and Borneo Rhino Sanctuary. In Sabah, the cost of constructing such a fence (concrete posts at 3 metre spacing, bracing posts at corners and slopes, five strands of steel cable, hot wire and netting) in a moderately remote forest site at time of writing is approximately US$80 per metre. Fencing for a 1,000 hectare sanctuary would thus cost around US$1 million. The only site of which we are aware suitable for such a large rainforest enclosure would be Way Kambas National Park. However, it is also vital to note that a fence which is a physical barrier may have significant adverse implications on a variety of other large terrestrial mammal species.

Some of the problematic issues associated with the large enclosure concept could be addressed by considering a location in a plantation, such as an oil palm plantation. The underlying concept of a big fenced enclosure on private land is well-accepted in America, Europe or Africa, but might be regarded as bizarre by some in Malaysia and Indonesia. It would be possible to build and maintain a robust perimeter fence along existing roads and terraces, irrespective of

Table 2. Possible ways to manage Sumatran rhinos, *Dicerorhinus sumatrensis*, in fenced facilities.

Option	Advantages	Issues of concern
Zoos	Very close monitoring possible. Sub-fertile rhinos can potentially receive treatment. Readily-identified diseases can be treated. Attempts at sperm collection, oocyte harvesting and artificial insemination can be done frequently.	Ideal diet may be difficult to ensure (Dedi et al, 2012). Clean clay soil for wallows required. Disease may result in mass mortality due to close proximity. Stress of close management may result in reduced fertility in some rhinos.
"Sanctuary": paddocks under natural forest with attached night stalls, already operational in Indonesia & Malaysia.	Very close monitoring possible (Andrianshah et al, 2013). Suitable food can be harvested from forest. Sub-fertile rhinos can potentially receive treatment. Readily-identified diseases can be treated. Attempts at sperm collection, oocyte harvesting and artificial insemination possible frequently.	Experienced veterinarians may not wish to commit to living out of town for very long periods.
Large enclosure (> 1,000 hectares) under rainforest.	Rhinos can develop their own home ranges and inter-actions with other rhinos. Rhinos choose their own foods. Low stress. Low risk of disease.	Site needs to be flat to allow construction and maintenance of perimeter fence (or, costly and with difficulty, a fence could be built following the boundary of a water catchment in a hill range). Site needs to be accessible by road and daily monitoring of perimeter fence achievable. Close monitoring of rhinos not possible. Supplementary minerals may be needed in case soils of chosen area are sub-optimum. Sub-fertile rhinos would better be managed in zoos or sanctuaries. Attempts at sperm collection, oocyte harvesting and artificial insemination not possible.
Large enclosure (> 1,000 hectares) on private land in Indonesia (e.g. abandoned plantation)	Perimeter fence can be constructed along existing roads or terraces. Site does not need to be flat. Woody weeds can be managed to provide partial food supply. Monitoring easier than in natural forest large enclosure due to road access and better visibility. Responsibility for costs and security shared with land-owner. Rhinos can develop their own home ranges and inter-actions with other rhinos. Relatively low stress and low risk of disease.	Herbicides cannot be used, and fertilizers with caution. Rhinos will need supplementary food from forest source. Piped water supply likely to be needed if natural watercourses not always present and clean. Close monitoring of rhinos not possible. Sub-fertile rhinos would better be managed in zoos or sanctuaries. Attempts at sperm collection, oocyte harvesting and artificial insemination not possible.

natural topography. In the absence of weeding, natural woody growth would provide some of the rhinos' food requirements. Responsibility for costs of developing and maintaining a large enclosure on private land and for security would need to be resolved, and potentially shared with the land-owner, which would most likely be a corporation.

Good and consistent husbandry and veterinary care are essential whichever option or combination of options is chosen. The willingness of experienced veterinarians to live on site, and indeed the availability of such veterinarians, are critical factors which may have a bearing on which model and location is chosen. Security will be a significant issue whatever option is chosen, and site-specific measures will need to be discussed and implemented.

Our suggestion is that the best solution is a combination of either the zoo / sanctuary model and the large enclosure forest or plantation model. All wild SR captured would be allocated to one or the other, based on their reproductive capability and other factors. Healthy, fertile SR could be allocated to the large enclosure, and other SR to the sanctuary or zoo.

We do not underestimate the challenges associated with working to achieve production of SR embryos by means other than natural breeding (Wildt and Wemmer, 1999), but history over the past century is replete with examples of people postulating that something cannot be done, a few years before that something is achieved. We must move purposefully towards making maximum use of assisted reproductive technologies on captive SR. Such experimental work could facilitate cost-sharing and potentially provide a useful conservation role for interested zoo authorities.

Conclusions

Based on our experience to date :

- Preventing the extinction of the SR rhino might not necessarily be achieved in the longer term by protecting wild rhinos.
- The emphasis on preventing poaching of wild SR has not been matched by serious efforts to maximise captive SR births. The latter is as much needed as the former in order to prevent extinction.
- SR can be captured and translocated from the wild with very low risk of mortality.
- SR can be sustained in good health in fenced facilities if veterinary care and dedicated keepers are always present under high quality management.
- SR can be bred in fenced facilities, both in zoos in temperate climates and in tropical rainforest forest paddocks.
- The occurrence of breeding in wild SR may be taken as reason to leave the rhinos in situ or, equally, as a great opportunity to capture and translocate some fertile wild rhinos into fenced facilities in order to increase the genetic diversity of the existing captive population and as part of the need to boost birth rates.
- Some wild SR live in places where capture and, crucially, removal from the forest will be logistically extremely difficult or impossible. The longer a decision to capture rhinos is delayed, the greater the likelihood that remaining rhinos will be in remote areas.
- Wild SRs which are not breeding are likely to be infertile or sub-fertile, and by capturing these rhinos, there is a chance to make use of their gametes for reproduction.
- If a decision is made to follow the African model of concentrating free-ranging rhinos in a large enclosure, the option to establish the enclosure in a plantation on private land is worthy of consideration.
- In general, the key elements of the best decisions can be made at any time, without waiting for better information on wild SRs.

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References

Ahmad, A.H., (1990) Kajian kelimpahan semasa dan beberapa aspek ekologi pemakanan bagi badak sumatera (Dicerorhinus sumatrensis harrissoni Groves) di kawasan pusat luar lembah Danum, Lahad Datu, Sabah. Thesis, Universiti Kebangsaan Malaysia, Kota Kinabalu pp. 1-38.

Aidi Mohamad, Vellayan, S.R., Radcliffe, W., Lowenstine, L.J., Epstein, J., Reid, S.A., Paglia, D.E., Radcliffe, R.M., Roth, T.L., Foose, T.J and Mohamad Khan, Momin Khan (2004). Trypanosomiasis (surra) in the captive Sumatran rhinoceros (*Dicerorhinus sumatrensis sumatrensis*) in Peninsular Malaysia. *Proceedings of the International Conference of the Association of Institutions for Tropical Veterinary Medicine* **11:**187-189

Andriansyah, Dedi Candra, Marcellus, A.C., Riyanto, T., Barry, J. and R.W. Robin (2013).Hematology and serum biochemistry of Sumatran rhinoceros (Dicerorhinus sumatrensis) in a rainforest sanctuary in Way kambas National Park, Indonesia. *Journal of Zoo and Wildlife Medicine* **44(2)**: 280–284.

Anon. (2013). http://cincinnatizoo.org/blog/2013/06/22/endangered-indian-rhinoceros-calf-conceived-by-artifical-insemination-born-at-the-montgomery-zoo/.

Bosi, E.J. (1996). Mating Sumatran rhinoceros at Sepilok Rhino Breeding Centre, Sandakan, Sabah, Malaysia. *Pachyderm* **21**: 24-27.

Brook, S., Coeverden, P. van, Mahood, S. and Long, B. (2011). Extinction of the Javan Rhinoceros (*Rhinoceros sondaicus*) from Vietnam. WWF-Vietnam.

Christman, J. (2010). Sumatran Rhinoceros International Studbook.

Courchamp, F., Berec, L. and Gascoigne, J. (2008) Allee effects in ecology and conservation. Oxford University Press, New York, USA.

Davies, A. G. and J. Payne (1982). A Faunal Survey of Sabah. WWF-Malaysia unpublished report.

Candra, D., Radcliffe, R.W., Andriansyah, Mohammad Khan, I-Hsien Tsu and D. E. Paglia (2012). Browse diversity and iron loading in captive Sumatran rhinoceroses (*Dicerorhinus sumatrensis*): a comparison of sanctuary and zoological populations. *Journal of Zoo and Wildlife Medicine* **43(3)**: S65–S72.

Flynn, R.W. and Tajuddin Abdullah, M., (1984). Distribution and status of the Sumatran rhinoceros in Peninsular Malaysia. *Biological Conservation* **28**: 253-273.

Furley, C.W. (1993). The clinical history of the adult female Sumatran rhinoceros, called 'Subur', in captivity in Sumatra and at Port Lympne zoo, Kent, Great Britain. pp. 357-366 in Ryder, O.A. 1993 Rhinoceros biology and conservation: Proceedings of an international conference, San Diego, U.S.A. San Diego, Zoological Society, pp. i-v, 1-368.

Goossens, B., Salgado-Lynn, M, Rovie-Ryan, J.J, Abdul H. Ahmad, Payne, J., Zainal Zahari Z., Senthilvel, K.S., Nathan, S. and L.N. Ambu (2013). Genetics and the last stand of the Sumatran rhinoceros Dicerorhinus sumatrensis. *Oryx* DOI: http://dx.doi.org/10.1017/S0030605313000045 Published online: 09 May 2013.

Groves, C. P. (1965). Description of a new subspecies of rhinoceros, from Borneo. *Saugetierkundliche Mitteilungen* **13(3)**: 128–131.

Harper, F., (1945). Extinct and vanishing mammals of the old world. New York, American Committee for International Wild Life protection (Special Publication, no. 12), i-xv, 1-850.

Hermes, R., Hildebrandt, T. B., Walzer, C., Göritz, F., Patton, M.L., Silinski, S., Anderson, M.J., Reid, C.E., Wibbelt, G., Tomasova, K. and F. Schwarzenberger (2006). The effect of long non-reproductive periods on the genital health in captive female white rhinoceroses (*Ceratotherium simum simum* and *C. s. cottoni*). *Theriogenology* **65**: 1492-1515.

Biography

Together, the authors of this paper have many years of unique experience of wild and captive SRs in Malaysia. Abdul Hamid Ahmad conducted field work on SR at Danum Valley in 1990 (Ahmad, 1990), when there were breeding female SRs near the Field Centre, and he has subsequently been a lecturer in wildlife biology in Sabah, taking a special interest in SR. Junaidi Payne's interest began with a survey of the SR population in the Endau Rompin forest of Peninsular Malaysia in 1977, guided by the late Nico van Strien. From 1979-86 and then 2005 to present, Junaidi Payne was actively involved in field surveys and conservation proposals for SR in Sabah. From 1980-84, he simultaneously worked on the establishment of Tabin Wildlife Reserve (for SR), and development of a SR captive breeding programme between Sabah and the American Association of Zoo Parks and Aquariums. The latter programme involved US assistance to build a rhino breeding facility in Sepilok, Sabah, with the first two pairs of rhinos to be held there, but the programme was rejected by the State Government in 1985 in favour of a wholly locally managed programme. Zainal Zahari Zainuddin joined the Peninsular Malaysia Department of Wildlife and National Parks in 1986 as a veterinarian, and was subsequently involved in capture, care, husbandry and/or breeding attempts of over 15 SR in Malaysia and Indonesia. In 2010, Zainal left government service and joined Junaidi Payne and Abdul Hamid Ahamd as veterinarian and field manager for the NGO, Borneo Rhino Alliance (BORA), which has as its sole goal the prevention of the extinction of the SR in Borneo (www.borneorhinoalliance.org).

Hermes, R., Goeritz, F., Saragusty, J., Sos, E., Molnar, V., Reid, C.E., Schwarzenberger, F. and T.B. Hildebrandt (2009a). First successful artificial insemination with frozen-thawed semen in rhinoceros. *Theriogenology* **71**: 393–399.

Hermes, R., Goeritz, F., Portas, T., Bryant, J.B.R., Kelly, J.M., Maclellan, L.J., Keeley, T., Schwarzenberger, F., Walzer, C., Schnorrenberg, A., Spindler, R.E., Saragusty, J., Kaandorp, S. and T.B. Hildebrandt (2009b). Ovarian superstimulation, transrectal ultrasound-guided oocyte recovery, and IVF in rhinoceros. *Theriogenology* **72**: 959–968.

Hornaday, W.T. (1887). The Extermination of the American Bison. Government Printing Office, Washington, USA.

Hubback, T. (1939). The Asiatic two-horned rhinoceros. *Journal of Mammalogy* **20(1)**: 1-20.

Kretzschmar, P., Sipangkui, R. and N.E. Schaffer (2009). Eye disorders in captive Sumatran rhinoceros (*Dicerorhinus sumatrensis harrissoni*) in Sabah, Malaysia. Proceedings of the international conference on diseases of zoo and wild animals 2009: 236-242.

Martin, T.G., Nally, S., Burbidge, A.A., Arnall, S., Garnett, S.T., Hayward, M.W., Lumsden, L.F., Menkhorst, P., McDonald-Madden, E. and Possingham, H.P. (2012). Acting fast helps avoid extinction. *Conservation Letters* **5(4)**: 274-280.

Medway, Lord (1977). Mammals of Borneo. Field keys and an annotated checklist. Monographs of the Malaysian Branch of the Royal Asiatic Society No. 7. Kuala Lumpur. xii + 172 pp.

Metcalfe, G.T.C. (1961). Rhinoceros in Malaya and their future: pp. 183-191, In: Wyatt-Smith, J. et al.. Nature conservation in western Malaysia, 1961. Special issue of the *Malayan Nature Journal*. Kuala Lumpur, Malayan Nature Society: pp. i-viii, 1-260.

Ng, J.S.C., Zainal-Zahari Z. and Adam Nordin (2001). Wallows and wallow utilization of the Sumatran rhinoceros (*Dicerorhinus sumatrensis*) in a natural enclosure in Sungai Dusun Wildlife Reserve, Selangor, Malaysia. *Journal of Wildlife and Parks* **19**: 7-12.

Nielsen, J. (2006). Condor: To the Brink and Back--the Life and Times of One Giant Bird. New York: HarperCollins Publishers.

Payne, J. (1990). The distribution and status of the Asian two-horned rhinoceros (*Dicerorhinus sumatrensis harrissoni*) in Sabah, Malaysia. Kuala Lumpur, WWF Malaysia (Report), pp. 1-33.

Pucek, Z., Belousova, I.P., Krasiñska, M., Krasiñski, Z.A. & Olech, W. (comps.). (2004) European Bison. Status Survey and Conservation Action Plan. IUCN/ SSC Bison Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

Rabinowitz, A. (1995). Helping a species go extinct: the Sumatran rhino in Borneo. *Conservation Biology* **9**: 482-488

Rookmaaker, L.C. (1977). The distribution and status of the rhinoceros, *Dicerorhinus sumatrensis*, in Borneo - a review. *Bijdragen tot de Dierkunde, Amsterdam* **47(2)**: 197-204.

Ryder, O.A. and E.A. Wedemeyer (1982). A cooperative breeding programme for the Mongolian wild horse *Equus przewalskii* in the United States. *Biological Conservation* **22(4)**: 259-271.

Saltz, D. (1998). A long-term systematic approach to planning reintroductions: the Persian fallow deer and the Arabian oryx in Israel. *Animal Conservation* **1(4)**: 245-252.

Saragusty, J. and A. Atav (2011). Current progress in oocyte and embryo cryopreservation by slow freezing and vitrification. *Reproduction* **141**: 1-19.

Schaffer, N.E., Zainal Zahari, Z., Suri, M.S.M., Jainudeen, M.R. and Jeyendran, R.S. (1994). Ultrasonography of the reproductive anatomy in the Sumatran rhinoceros (*Diceorhinus sumatrensis*). *Journal of Zoo and Wildlife Medicine* **25(3)**: 337-348.

Schaffer, N.E., Agil, M. and E. Bosi (2001). Utero-ovarian pathological complex of the Sumatran Rhinoceros (*Dicerorhinus sumatrensis*). In Abstracts of the International Elephant and Rhino Research Symposium, (eds H.M. Schwammer, T. J. Foose, M. Fouraker and D. Olson), pp.322. Vienna, Austria.

Skinner, J.D. and C.T. Chimimba (2006). The Mammals of the Southern African Sub-region. 3rd Edition. Cambridge University Press.

Spalton, J.A. (1999). The food supply of Arabian oryx (*Oryx leucoryx*) in the desert of Oman. *Journal of Zoology* **248**: 433–441.

Stoops, N., Bateman, H.L., Campbell, M.K. and T.L. Roth (2011). Attempted in vitro maturation and fertilization of post-mortem Sumatran Rhinoceros (*Dicerorhinus sumatrensis*) oocytes. *Journal of Zoo and Wildlife Medicine* **42(4)**: 723–726.

Strien, N.J. van, (1975). *Dicerorhinus sumatrensis* (Fischer), the Sumatran or two-horned rhinoceros: a study of literature. *Mededelingen van de Nederlandse Commissie voor Internationale Natuurbescherming* **22**: 1-82.

USFWS (2008). Black-footed Ferret (*Mustela nigripes*) 5-Year Status Review: Summary and Evaluation. US Fish & Wildlife Service South Dakota Field Office, Pierre, South Dakota.

Wildt, D. and C. Wemmer (1999). Sex and wildlife: the role of reproductive science in conservation. *Biodiversity and Conservation* **8(7)**:965-976.

Zainal Zahari, Z. (1995). Review of Sumatran rhinoceros *Dicerorhinus sumatrensis* population in Peninsular Malaysia. *Journal of Wildlife and Parks*. **14**: 1-15.

Zainal Zahari, Z., Tajuddin Abdullah, M. and M. Shamsuddin M. Suri (1990). The Husbandry and Veterinary Care of Captive Sumatran Rhinoceros at Zoo Melaka, Malaysia. *Malayan Nature Journal* **44**: 1-19.

Zainal Zahari, Z., Ng J.S.C., Nasaruddin, O. and Ahmad Azhar, M. (2001). Displacement of Asian Elephants *Elephas maximus*, Sumatran Rhinoceroses *Dicerorhinus sumatrensis* and Malayan Tapirs *Tapirus indicus* in Peninsular Malaysia. *Journal of Wildlife and Parks*. **19**: 13-18.

Zainal Zahari, Z., Rosnina, Y., Wahid, H., Yap, K.C. and M.R. Jainudeen (2005). Reproductive behaviour of captive Sumatran rhinoceros (*Dicerorhinus sumatrensis*). *Animal Reproduction Science* **85**: 327–335.