Landscape-level assessment of the distribution of the Sumatran rhinoceros in Bukit Barisan Selatan National Park, Sumatra

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Abstract

We conducted the first systematic survey on Sumatran rhinoceros following a robust patch occupancy framework in 3,500 km^2 of Bukit Barisan Selatan National Park (BBSNP), Sumatra, Indonesia. We surveyed 55 grids (72.25 km^2) between November 2007 and July 2008 to generate a reliable estimate of the proportion of area occupied (occupancy) by the Sumatran rhinoceros. Rhinoceros signs, e.g. footprints, dung, tree twists and wallows, were recorded along 833 km of transect routes, and 1-km sampling interval was used to develop detection/non-detection history for each grid. Rhinoceros signs were detected on 11 grids producing a naïve occupancy of 0.2. Occupancy modelling was used to control for imperfect detection probability (P). Based on the Royle/Nichols Heterogeneity model we concluded that Sumatran rhinoceros occupied approximately 32% of the BBSNP area (SE = 0.09). Occupancy can serve as a robust surrogate for an index of abundance in a population-monitoring framework. Further analysis using the multi-season models of the technique on time series data and season/survey-specific covariates can provide management authorities with accurate information about changes in rhinoceros populations and assist in prioritizing conservation actions for the Sumatran rhinoceros in the region.

Résumé

Nous avons mené une première enquête systématique sur les rhinocéros de Sumatra en suivant un cadre robuste d'occupation du territoire sur une superficie de 3500 km^2 du Parc national de Bukit Barisan Selatan (PNBBS à Sumatra en Indonésie. Nous avons étudié 55 grilles (72,25 km^2) entre novembre 2007 et juillet 2008 pour produire une estimation fiable de la proportion de la superficie occupée (occupation) par le rhinocéros de Sumatra. On a enregistré des signes de rhinocéros (par exemple, des empreintes, des crottes, des torsions d'arbres et des vautrements) le long de 833 km des transects et on a utilisé l'intervalle d'échantillonnage de 1 km afin de développer une histoire de détection/non-détection pour chaque grille. On a détecté des signes de rhinocéros dans 11 grilles produisant une occupation naïve de 0,2. Une modélisation de l'occupation a été utilisée pour contrôler la probabilité de détection imparfaite (P). En se basant sur le modèle d'hétérogénéité de Royle/Nichols, nous avons conclu que le rhinocéros de Sumatra occupait environ 32% de la superficie du PNBB (SE = 0,09). L'occupation peut servir comme un substitut robuste pour un indice d'abondance dans un cadre de surveillance de la population. Une analyse plus approfondie utilisant les modèles multi-saisonniers de la technique sur les données de séries chronologiques et des covariables spécifiques saisonnières/par études peuvent fournir aux autorités de gestion des informations précises sur l'évolution des populations de rhinocéros et aider à prioriser les mesures de conservation pour le rhinocéros de Sumatra dans la région.

Introduction

No other group of animals has been so highly prized for so long yet also managed to survive human onslaught as the rhinoceros has (Rabinowitz 1995). With their horn valued higher than gold (Gwin 2012) and much of their range converted to plantation, it is amazing that rhinoceros have survived into this century. There are five extant species of rhinoceros in the world: two in Africa—white rhinoceros *Ceratotherium simum* and black rhinoceros *Diceros bicornis*—and three in Asia—Indian rhinoceros *Rhinoceros unicornis,* Javan rhinoceros *Rhinoceros sondaicus* and Sumatran rhinoceros *Dicerorhinus sumatrensis*. The Sumatran rhinoceros is the smallest and most primitive of all extant rhinoceros species (Dinerstein 2003). Once distributed throughout South and Southeast Asia (Foose and van Strien 1997), they are now confined to isolated parts of Indonesia and Malaysia: *D.s. sumatrensis* occurs in Sumatra and Peninsular Malaysia and *D.s. harrissoni* is endemic to Borneo (Ahmad Zafir et al. 2011). The failure of the Sumatran Rhino Trust in the late 1980s (Doherty 1992; Hutchins 1995; Lessee 1995) has become the source of the 'parks or arks' debate on Sumatran rhinoceros conservation. Rabinowitz (1995) cautioned that money and effort spent on the capture and breeding programme would not solve the problem nor remove the causal factors of rhinoceros decline in the wild. He summarized by asking rhetorically, 'After all these years, do we know how many Sumatran rhinoceros we are dealing with?' Surprisingly, 18 years have passed and the answer is still no.

By learning from the black rhinoceros captive breeding effort (Balmford et al. 1995), one can see that in situ conservation provides a greater benefit for species and ecosystem. The captive breeding programme for black rhinoceros costs three times more than protecting them in the wild, while recruitment was also higher in protected wild populations than with the captive one (Balmford et al. 1995). Establishing rhinoceros protection units (RPU) in Sumatra in 1995 became a crucial step in securing this species in the wild in three national parks: Kerinci Seblat and Bukit Barisan Selatan, and later in Way Kambas in 1998. After 17 years, Sumatra is now the only place where a wild population of Sumatran rhinoceros still persists. In contrast, rhinoceros have been ecologically extinct from habitats where no RPUs were operated, including Peninsular Malaysia (Clements et al. 2010; Ahmad Zafir et al. 2011) and Borneo (Payne and Ahmad 2012; Nichols 2012).

To be successful, managers need effective tools to evaluate and measure the outcome of their conservation interventions (Buckland et al. 2005). So far, the success of Sumatran rhinoceros protection has been evaluated by the number of illegal activities encountered (traps destroyed and poachers apprehended) (Isnan et al. 2007). However, the relationship between the rate of illegal activities and rhinoceros population parameters is unknown. In 1998, a univariate multiple comparison procedure was performed on rhinoceros footprint morphometrics, resulting in an estimate of 30–43 rhinoceros throughout the surveyed area (Wibisono 1998). A further attempt to estimate population status was a trend of abundance indices between 2002 and 2005 (Pusparini 2006). This study suggested that density estimation of Sumatran rhinoceros using photographic identification was not feasible due to lack of unique physical characteristics and extremely low capture rate. The most recent estimate of rhinoceros number in Bukit Barisan Selatan National Park (BBSNP) was 60–70 individuals, based on an educated guess (Rubianto and Suratman 2008; Talukdar et al. 2010).

Individual identification from rhinoceros footprints has proven to be reliable (van Strien 1985) and widely used on African rhinoceros (Alibhai et al. 2008). However, this technique usually deals with the problem of the low number of footprints being distinguished (van Strien 1986; Alibhai et al. 2008). Therefore, practical factors restrict the application of this method over a vast landscape. Population estimate using faecal DNA has been tested on Javan rhinoceros (Foead 1997; Fernando et al. 2006), Indian rhinoceros (Borthakur 2009), white rhinoceros (Steyn and Stalmans 2004), and black rhinoceros (Cunningham et al. 2001; de Groot et al. 2011). Nevertheless, the cost and time spent in analysing genetic materials make its application for large-scale monitoring not feasible.

Many population assessments do not consider two important sources of variability: spatial variation and detectability, resulting in uncertain relationship between the count statistic and the true population (MacKenzie and Kendall 2002; MacKenzie 2003; MacKenzie and Nichols 2004; O'Connell et al. 2006). The underlying questions of biological monitoring are how is biodiversity changing over time and at what rate? Without addressing such questions, there is little prospect of implementing effective action to prevent population decrease (Buckland et al. 2005). Occupancy approach (MacKenzie et al. 2002; MacKenzie and Nichols 2004; MacKenzie et al. 2005; MacKenzie and Royle 2005; MacKenzie et al. 2006) is considered superior over other methods commonly used for large mammals in terms of robustness, time, cost effectiveness and area coverage. It is especially appropriate for low-density, wide-ranging cryptic mammals such as the Sumatran rhinoceros. The occupancy method has been proven successful in investigating wildlife population status ranging through salamanders (Bailey et al. 2004), tigers (Linkie et al. 2006; Wibisono et al. 2011) and African rhinoceros (Tosh et al. 2004). Therefore, we consider it as the most feasible and appropriate approach, especially to assess the distribution pattern of Sumatran rhinoceros over a large landscape (Karanth and Nichols 2010).

Study area

This study was carried out between November 2007 and July 2008 in BBSNP (3,650 km^2), the third largest national park in Sumatra. The park stretches along 150 km of the Bukit Barisan Mountains from Lampung Province (82% of the area) to Bengkulu and contains the largest lowland tropical evergreen forest in Sumatra (Gaveau et al. 2006). This part of Sumatra has been experiencing a dramatic human population increase since the 1930s and losing its forests faster than any other Sumatran region (Benoit and Indonesia Departement ORSTOM 1989). The long and narrow shape of the park results in a 700-km boundary and extensive development activity, especially small-scale agriculture and logging within and along the boundary of the park (O'Brien and Kinnaird 1996). As a consequence, 661 km^2 (18%) of forest cover disappeared from the park between 1985 and 1999 (Kinnaird et al. 2003), mainly due to agricultural encroachment (Gaveau et al. 2006).

Methods

The basic design of the survey followed the landscape-wide patch occupancy protocol (Karanth and Nichols 2010). A grid of 72.25 km^2 was used as a sampling unit to reflect the largest home range of the Sumatran rhinoceros, measuring 60 km^2 (van Strien 1986). A total of 55 imaginary grids was overlaid over the BBSNP. Four teams of four technicians were employed to search along paths having the highest probability to find rhinoceros signs. To provide an element of randomness, a smaller cell of 18 km^2 was randomly chosen in each grid for the survey team to traverse. Presence of rhinoceros signs was recorded along 833 km of irregular transects, resulting in an average of 15.15 km/grid (min. 1 km, max. 56 km). Next, 1-km replicates were used to develop a detection matrix of '1' and '0', each representing detected and not detected. Further, not all sampling units had the same proportion of unsuitable area (e.g. sea or human settlement), resulting in different transect lengths among grids. In the detection matrix, detection history of a grid with the longest transect represents a full trial. Therefore, missing values were assigned onto the detection histories of grids with shorter transects, which contribute nothing as they are treated as 0 by the log-likelihood function (Royle and Dorazio 2008). To estimate the probability that a grid was occupied by rhinoceros and its presence was detected, we used a multinomial maximum likelihood procedure (MacKenzie et al. 2006).

We performed a single season constant model and the Royle/Nichols Heterogeneity model to estimate the proportion of area occupied by rhinoceros across the park. The single-season constant model estimates a proportion of area occupied (*psi*) by animals assuming the detection probability (*P*) to be constant across sites. The Royle/Nichols Heterogeneity model estimates a proportion of area occupied by animals as a function of some heterogeneity in the detection probability across sites (Royle and Nichols 2003). Data analysis was performed using PRESENCE var. 4.5 (Hines 2006). Kernel density estimator in ArcGis 10.1 was performed on rhinoceros localities to generate a predictive map of rhinoceros distribution in BBSNP. Kernel density calculates the density of point features by fitting a smoothed surface curve over each point. A searching radius of 5 km was used to represent the size of the sampling unit. The surface value is highest at the point of rhinoceros occurrence and reaches zero at the end of the circle.

Results

Rhinoceros signs were detected in 11 out of 55 grids, giving a naïve occupancy of 0.2. The detection probability of the single-season constant model was higher than with the Royle/Nichols Heterogeneity model with 0.15 ± 0.04 and 0.10 ± 0.023 respectively. This resulted in a lower proportion of area occupied for the single season constant model with 0.30 (0.08) than with the Royle/Nichols Heterogeneity model with 0.32 (0.09). The Royle/Nichols Heterogeneity model estimated an abundance of 21 (± 7.1) rhinoceros living in the park. The kernel density map showed that most rhinoceros were distributed in the middle part of the park and segregated into three groups in the Sukaraja, Way Ngaras and Kubu Perahu areas (Figure 1).

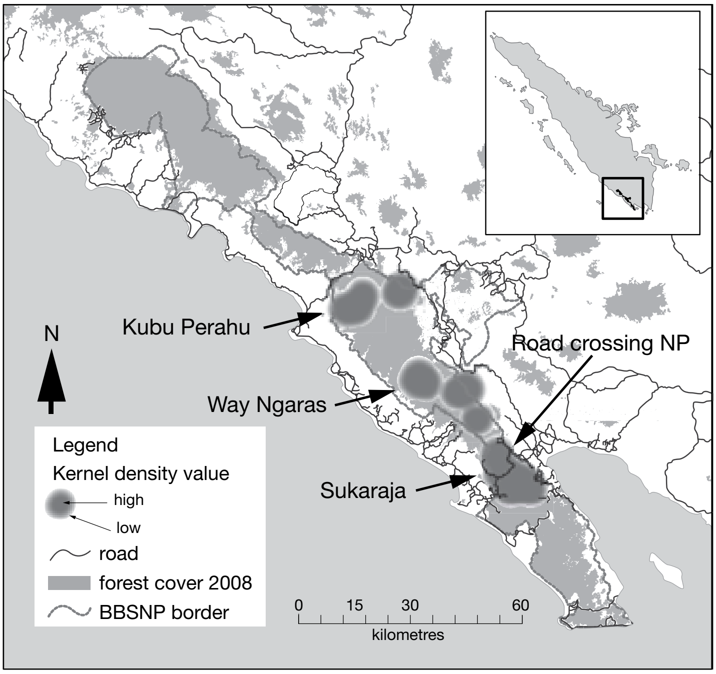

Figure 1. Kernel density estimation of rhinoceros signs. Inset, the study area in Indonesia.

Discussion

Estimating the proportion of area occupied by animals needs to consider variation in the detection probability as a function of season and survey-specific covariates, and abundance-induced heterogeneity. Not incorporating potential covariates into a model will overlook source of heterogeneity in an ecological system. Since we did not incorporate covariates, we modelled variation in detection probability using the Royle/Nichols Heterogeneity model. Our analysis showed that unmodelled heterogeneity of detection probability in the single season constant model underestimated the occupancy estimate.

Sumatran rhinoceros numbers have continued to decline at a rapid rate with a loss of 50% or more of the population between 1985 and 1995 (Foose and van Strien 1997). The total number of Sumatran rhinoceros was estimated to be between 250 and 390 in 1993, which had dwindled to 147–220 in 2007 (MoF 2007). Many of these estimates, however, were simply educated guesses and hence must be treated with caution. Attempts to conserve rhinoceros might be hindered by insufficient information to document the species' population status. Despite the obvious reasons for monitoring rhinoceros populations, no comprehensive population survey has been implemented in Sumatra due to lack of resources and expertise.

In this study we conducted the first systematic survey for Sumatran rhinoceros in BBSNP and provided a robust population parameter estimate. The parameter was estimated using a patch occupancy framework, directly dealing with two sources of variations commonly found on a sampling design: space and detectability (MacKenzie et al. 2002). In terms of space, many designs seek to provide inferences about an area by sampling only a portion of it because the area is too large to be completely surveyed. The selection of representative small areas permits inference to the entire area of interest. In contrast, an occupancy survey allows for a large-scale monitoring programme by estimating the proportion of sampled area occupied by a species, which is easier and less expensive than the method used for abundance estimation (MacKenzie et al. 2002). The occupancy of 0.32 implies that only 32% (1,000 km^2) of suitable habitat in the park was occupied by rhinoceros during 2007–2008. For BBSNP, the Indonesian Rhinoceros Action Plan (MoF 2007) indicated that, to be viable in the long term, the Sumatran rhinoceros requires a minimum of 1,000 km^2. Our result suggests that the rhino population in the park occupied a minimum size of suitable habitat required to be viable for the long run. However, this study also shows that this rhinoceros population was fragmented into three sub-populations. Thus, unless proper actions are immediately put in place, the wild rhinoceros population in BBSNP will certainly disappear in the near future.

This study provides sound baseline data needed for a long-term biological monitoring scheme in BBSNP, a park with potentially the highest population of Sumatran rhinoceros in the world (Indonesia 2007). Repeating the survey using the robust multi-seasons occupancy framework (MacKenzie et al. 2005) would provide the park management with a robust evaluation capacity for conservation management and intervention. Other than the proportion of occupancy and detection probability, the multi-seasons patch occupancy approach provides an estimate of local extinction and colonization between seasons. In general, occupancy may be a function of site-specific covariates that are constant throughout the season (e.g. habitat type), while detection probabilities may also be a function of covariates that change through season (e.g. weather conditions) (MacKenzie et al. 2005). A number of covariates measured at each site can be incorporated into the model to find the best fitted model that describes the data using a logistic model (MacKenzie et al. 2002; MacKenzie et al. 2003).

The Indonesian Rhinoceros Action Plan plans to expand the wild rhinoceros population in Bukit Barisan Selatan, Gunung Leuser and Way Kambas National Parks by at least 30% (MoF 2007). The kernel density shows that the rhinoceros were largely distributed in the central part of the park (Figure 1). In 2006, the development of an asphalt road crossing the Sukaraja area (Sanggi to Bengkunat) appeared to have a negative effect on several wildlife species, including the rhinoceros. The detrimental effect of a road inside a protected area has been demonstrated in many other studies (Bennett and Robinson 2000; Kerley et al. 2002; Linkie et al. 2006). Infrastructure development right in the centre of rhinoceros distribution would be disastrous for the population in the long term. Therefore, we urge the management authority to implement a ‘rhinoceros friendly’ road system. This may be done by developing underpasses that facilitate rhinoceros movement, controlling road uses, conducting routine patrols, and establishing active road block enforcements to control illegal activities facilitated by the road. The national park and partners also urgently need to implement a new adaptive protection scheme (Stokes 2010).

There are many examples where critically endangered species became extinct locally due to inadequate knowledge of their population status, including tigers in Sariska, India (Karanth 2011) and in the Seima Protection Forest, Cambodia (O’Kelly et al. 2012), and Sumatran rhinoceros in Kerinci Seblat NP (Isnan 2006). Therefore, a monitoring scheme based on a robust scientific approach is crucial as an evaluation tool for conservation interventions. Our study highlighted one of the main weaknesses of rhinoceros conservation approaches in the park: the absence of robust biological monitoring practices. While the proposed technique does not provide a point of estimate of rhinoceros numbers, our finding strongly indicated that the rhinoceros population in BBSNP may not have been as healthy as what we have believed so far with 60–70 individuals (Talukdar et al. 2010). Thus, we recommend: 1) the method of population monitoring based on occupancy approach be integrated in Sumatran rhinoceros conservation, 2) the adaptive protection scheme be implemented, and 3) the green infrastructure be implemented to all existing and future developments inside the park.

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References

Ahmad Zafir AW, Mohamed A, Lau CF, Sharma DSK, Payne J, Alfred R, Williams AC, Nathan S, Ramono WS, Clements GR. 2011. Now or never: what will it take to save the Sumatran rhinoceros *Dicerorhinus sumatrensis* from extinction? *Oryx* 45:225–233.

Alibhai SK, Jewell ZC, Law PR. 2008. A footprint technique to identify white rhinocerus *Ceratotherium simum* at individual and species levels. *Endangered Species Research* 4:205–218.

Bailey LL, Simons TR, Pollock KH. 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. *Ecological Applications* 14:692–702.

Balmford A, Leader-Williams N, Green MJB. 1995. Parks or arks—where to conserve threatened mammals. *Biodiversity and Conservation* 4:595–607.

Bennett EL, Robinson JG. 2000. *Hunting of wildlife in tropical forests: implications for biodiversity and forest peoples.* World Bank, Washington, DC. p. 56.

Benoit D, Indonesia Departement ORSTOM. 1989. Transmigration et migrations spontanees en Indonesie: Propinsi Lampung (Transmigration and spontaneous migrations in Indonesia: Propinsi Lampung). ORSTOM: Departement Transmigrasi Bondy, France; Jakarta Selatan, Indonesia.

Borthakur U. 2009. Non-invasive population genetic monitoring of Indian rhinoceros in Assam: a pilot study to standardise protocols for dung DNA analysis. *The Rhino Print (Newsletter of the Asian Rhino Project)* 4:6–7.

Buckland ST, Magurran AE, Green RE, Fewster RM. 2005. Monitoring change in biodiversity through composite indices. *Philosphical Transactions of the Royal Society B*, 360:243–254.

Clements R, Rayan DM, Zafir AWA, Venkataraman A, Alfred R, Payne J, Ambu L, Sharma DSK. 2010. Trio under threat: can we secure the future of rhinos, elephants and tigers in Malaysia? *Biodiversity and Conservation* 19:1115–1136.

Cunningham J, Morgan-Davies AM, O'Ryan C. 2001. Counting rhinos from dung: a method to estimate the minimum number of animals present in a protected area using microsatellite DNA. *South African Journal of Science* 97:293–294.

de Groot PJVC, Putnam AS, Erb P, Scott C, Melnick D, O'Ryan C, Boag PT. 2011. Conservation genetics of the black rhinoceros, *Diceros bicornis bicornis*, in Namibia. *Conservation Genetics* 12:783–792.

Dinerstein E. 2003. *The return of the unicorns: the natural history and conservation of the greater one-horned rhinoceros*. Columbia University Press, New York.

Doherty JG. 1992. Saving species: the Sumatran Rhino Trust. *Zoo View* 26:24–27.

Fernando P, Polet G, Foead N, Ng LS, Pastorini J, Melnick DJ. 2006. Genetic diversity, phylogeny and conservation of the Javan rhinoceros *(Rhinoceros sondaicu*s). *Conservation Genetics* 7:439–448.

Foead N. 1997. Faecal DNA analysis: what does it offer to save Javan rhino? In: Foose TJ and van Strien NJ, editors, *Javan Rhino Colloquium: agenda and briefing book*. Editorial Committee, Bogor. p. 15.

Foose TJ, van Strien N. 1997. *Asian rhinos—status survey and conservation action plan.* IUCN, Gland, Switzerland, and Cambridge, UK.

Gaveau DLA, Wandono H, Setiabudi F. 2006. Three decades of deforestation in southwest Sumatra: have protected areas halted forest loss and logging, and promoted re-growth? *Biocon* 8.

Gwin P. 2012. Rhino wars. *National Geographic* 221:106–120.

Hines JE. 2006. PRESENCE2: software to estimate patch occupancy and related parameters. US Geological Survey, Patuxent Wildlife Research Center, Laurel, MD. http://www.mbr-pwrc.usgs.gov/software/presence.shtml.

Hutchins M. 1995. Sumatran rhino conservation. *Conservation Biology* 9:977–977.

Isnan MW. 2006. Laporan Penyelamatan Badak Sumatera Taman Nasional Kerinci Seblat di Bengkulu. In: PHKA Kementrian Kehutanan, Bogor, Indonesia. p. 36.

Isnan W, Subrata D, van Strien NJ. 2007. Quarterly activity and performance report, 1 January–31 March 2007 (Q1). p. 28.

Karanth KU. 2011. India's tiger counts: the long march to reliable science. *Economic and Political Weekly* 46:22–24.

Karanth KU, Nichols JD. 2010. Non-invasive survey methods for assessing tiger populations. In: Tilson RL, Nyhus PJ, editors., *Tigers of the world: the science, politics, and conservation of* Panthera tigris. Elsevier/Academic Press, Boston. pp. 241–261.

Kerley LL, Goodrich JM, Miquelle DG, Smirnov EN, Quigley HB, Hornocker MG. 2002. Effects of roads and human disturbance on Amur tigers. *Conservation Biology* 16:97–108.

Kinnaird MF, Sanderson EW, O'Brien TG, Wibisono HT, Woolmer G. 2003. Deforestation trends in a tropical landscape and implications for endangered large mammals. *Conservation Biology* 17(1):245–257.

Lessee J. 1995. Sad news [Sumatran rhino in San Diego]. *Really Rhinos* 9:1.

Linkie M, Chapron G, Martyr DJ, Holden J, Leader-Williams N. 2006. Assessing the viability of tiger subpopulations in a fragmented landscape. *Journal of Applied Ecology* 43:576–586.

MacKenzie DI. 2003. Assessing site occupancy modelling as a tool for monitoring Mahoenui giant meta populations. *DOC Science Internal Series* 145.

MacKenzie DI, Kendall Wl. 2002. How should detection probability be incorporated into estimates of relative abundance? *Ecology* 83:2387–2393.

MacKenzie DI, Nichols JD. 2004. Occupancy as a surrogate for abundance estimation. *Animal Biodiversity and Conservation* 27:461–467.

MacKenzie DI, Nichols JD, Hines JE, Knutson MG, Franklin AB. 2003. Estimating site occupancy, colonization and local extinction when a species is detected imperfectly. *Ecology* 84:2200–2207.

MacKenzie DI, Nichols JD, Lachman GB, Droege S, Royle JA, Langtimm CA. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83:2248–2255.

MacKenzie DI, Royle JA. 2005. Designing occupancy studies: general advice and allocating survey effort. *Journal of Applied Ecology* 42:1105–1114.

MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey LL, Hines JE. 2006. *Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence*. Elsevier/Academic Press, Burlington, MA.

MacKenzie DI, Nichols JD, Sutton N, Kawanishi K, Bailey Ll. 2005. Improving inferences in population studies of rare species that are detected imperfectly. *Ecology* 86:1101–1113.

[MoF] Ministry of Forestry. 2007. Stretgy and action plan for the conservation of rhinos in Indonesia. MoF, Republic of Indonesia.

Nichols, H. 2012. Sex and the single rhinoceros. *Nature* 485:566–569.

O'Brien TG, Kinnaird MF. 1996. Birds and mammals of the Bukit Barisan Selatan National Park, Sumatra, Indonesia. *Oryx* 30:207.

O'Connell AF, Talancy NW, Bailey LL, Sauer JR, Cook R, Gilbert AT. 2006. Estimating site occupancy and detection probability parameters for meso- and large mammals in a coastal ecosystem. *Journal of Wildlife Management* 70:1625–1633.

O'Kelly HJ, Evans TD, Stokes EJ, Clements TJ, Dara A, Gately M, Menghor N, Pollard EHB, Soriyun M, Walston J. 2012. Identifying conservation successes, failures and future opportunities; assessing recovery potential of wild ungulates and tigers in eastern Cambodia. *PLoS One*, 7 e40482.

Payne, J, Ahmad AH. 2012. A comment on 'sex and the single rhinoceros' by Henry Nichols. http://www.borneorhinoalliance.org

Pusparini W. 2006. Population and habitat feasibility study of the Sumatran rhino (*Dicerorhinus sumatrensis,* Fischer 1814) at Bukit Barisan Selatan National Park. Thesis. Faculty of Math and Science, University of Indonesia Depok, p. 109.

Rabinowitz A. 1995. Helping a species go extinct—the Sumatran rhino in Borneo. *Conservation Biology* 9:482–488.

Royle, JA, Nichols JD. 2003. Estimating abundance from repeated presence–absence data or point counts. *Ecology* 84:777–790.

Royle JA, Dorazio RM. 2008. *Hierarchical modeling and inference in ecology: the analysis of data from populations, metapopulations and communities*. Academic, Amsterdam, Burlington, MA.

Rubianto A, Suratman. 2008. *Konservasi dan dugaan populasi badak sumatera (*Dicerorhinus sumatrensis, *Fischer 1814) di Taman Nasional Bukit Barisan Selatan.* RPU-YABI, TNBBS Kota Agung.

Steyn A, Stalmans M. 2004. Use of DNA technology in white rhino *(Ceratotherium simum)* identification and its applications in conservation. *Game and Wildlife Science* 21:787–795.

Stokes EJ. 2010. Improving effectiveness of protection efforts in tiger source sites: developing a framework for law-enforcement monitoring using MIST. *Integrative Zoology* 5:363–377.

Talukdar BK, Sectionov, Whetham LB, editors. 2010. *Proceedings of the Asian Rhino Specialist Group meeting held at Kaziranga National Park, India, 10–12 February 2010*. p. 30.

Tosh CA, Reyers B, Jaarsveld AS. 2004. Estimating the abundances of large herbivores in the Kruger National Park using presence–absence data. *Animal Conservation* 7:55–61.

van Strien NJ. 1986. *The Sumatran rhinoceros,* Dicerorhinus sumatrensis *(Fischer, 1814), in the Gunung Leuser National Park, Sumatra, Indonesia: its distribution, ecology and conservation*. P Parey, Hamburg.

Wibisono HT. 1998. *Laporan Akhir Monitoring Badak Sumatera TN Bukit Barisan Selatan.* RPU - PKBI Kota Agung. Unpublished.

Wibisono HT, Linkie M, Guillera-Arroita G, Smith JA, Sunarto, Pusparini W, Asriadi, Baroto P, Brickle N, Dinata Y et al. 2011. Population status of a cryptic top predator: an island-wide assessment of tigers in Sumatran rainforests. *PloS One* 6.