NOTES

Estimating the population structure of Javan rhinos (*Rhinoceros sondaicus*) in Ujung Kulon National Park using the mark-recapture method based on video and camera trap identification

Adhi Rachmat Sudrajat Hariyadi[1], Agus Priambudi[2], Ridwan Setiawan[3], Daryan Daryan[4], Asep Yayus[5] and Hendra Purnama[6]*

[1,3]WWF Indonesia, Jl Halmahera No. 9 Villa Admiral Lippo Carita km 8, Labuan-Pandeglang 42264, Banten, Indonesia

[2,4,5,6]Ujung Kulon NP Authority, Jl Perintis Kemerdekaan No. 51 Labuan – Pandeglang Banten Indonesia 42264

*Corresponding author: ahariyadi@cbn.net.id

Abstract

The population structure of the Javan rhino (*Rhinoceros sondaicus*) in Ujung Kulon National Park (NP) in Banten, Indonesia was assessed using visual identification and mark-recapture estimation. The software program CAPTURE was used for selecting the best fit estimator for the mark-recapture calculation and yields M(th) as the best model. The software results delivered a mean estimation of 32 rhinos (a minimum of 29 and maximum of 47 rhinos) with a 95% confidence level based on the dataset obtained from April 2008 to September 2009. The visual identification suggests that the current population in Ujung Kulon NP is male biased by a 3:2 sex ratio of males versus females. The demography shows that the population consists of mainly adult individuals that have a tendency of 1% population growth per year.

Key words: Javan rhino, population, mark-recapture, population estimation, camera trap

Résumé

La structure de la population du rhinocéros de Java (*Rhinoceros sondaicus*) dans le parc national d'Ujung Kulon à Banten en Indonésie a été évaluée en utilisant l'identification visuelle et une estimation de capture-marquage-recapture. Le logiciel CAPTURE a été utilisé comme le meilleur modèle pour sélectionner le meilleur estimateur propre au calcul et aux rendements M (th) de capture-marquage-recapture. Les résultats du logiciel ont donné une estimation moyenne de 32 rhinocéros (un minimum de 29 et un maximum de 47 rhinocéros) avec un niveau de confiance de 95% d'après la série de données obtenues d'avril 2008 à septembre 2009. L'identification visuelle suggère que la population actuelle dans le parc national d'Ujung Kulon est biaisée en faveur des mâles avec un rapport de 3 mâles contre 2 femelles. La démographie montre que la population se compose principalement d'individus adultes qui ont une tendance de croissance de 1% par an.

Introduction

The main indicators of success in conserving an endangered wildlife species are the population size and the net population growth. The Indonesian government set the growth of the Javan rhino population at a rate of 3% annually in order to achieve the conservation goal set in the Indonesian Rhino Conservation Strategy (PHKA, 2007). Unfortunately, the existing condition of the habitat (dense forest) and the scarce distribution Javan rhinos do not allow the application of census methods to obtain exact counts such as those like direct counts, which can be implemented for deer and pheasants (Lewis, 1970), or using aerial counts as done for wildlife in the Serengeti-Mara region (Talbot & Stewart, 1964). Fortunately, the distribution of Javan rhinos has been extensively studied (Hoogerwerf, 1970; Muntasib, 2002), so there is no immediate need for conducting a patch occupancy survey, which would tend to have a bias due to the inability of this method to accurately detect the presence of an animal in a given survey area if not done repeatedly (Mackenzie & Royle, 2005). Due to the difficulties in applying a direct count/exact count, the existing conditions for Javan rhinos should only rely on a relatively accurate estimation of population structure, instead of on exact counts.

One method that offers relatively accurate population estimates of wildlife species is the mark-recapture calculation based on visual identification, as done on tiger populations in India (Karanth & Nichols, 2002). The use of camera traps for visual identification of rhinos in Ujung Kulon NP was initiated by Griffith (1993), and was followed by Yahya (2002) to study the distribution and by Hariyadi et al. (2010) to study the behaviour of the Javan rhinos directly in their habitat.

The Javan rhino is known to have frequent wallowing behaviour because moisture/water is required to ensure the integrity of their epidermis (Shadwick et al., 1992), as well as for thermoregulation (Schenkel & Schenkel-Hullinger, 1969). Failure to wallow will lead to dryness that could eventually lead to pathological conditions and pain in the epidermal tissue (Munson et al., 1998). The need to wallow for both male and female Javan rhinos in Ujung Kulon NP is indicated by the daily wallowing behaviour recorded in previous observations (Schenkel et al., 1969; Hoogerwerf, 1970; Sajudin, 1984). There is no known sexual dimorphism in the epidermal tissue, and no differences in wallow frequencies between male and female Javan rhinos have been reported. The differences of wallow frequencies between males and females are assumed to be very little based on findings from Yahya (2002), so they should show similar wallowing frequencies and probabilities. If this is true, there will not be a sex bias to take into account with the survey design.

In using mark-recapture estimation of the population size, it is important to determine the population closure during the survey period. Population closure is defined using two categories—the demographic closure and the geographic closure (White et al., 1982). Since the movement trends of Javan rhinos have been previously recorded in Yahya (2002) and Setiawan and Yahya (2002), the geographic closure for the Javan rhino population can be defined. However, due to the occurrence of births and mortality during the survey period, the demographic closure principles may not be fulfilled in this study (White et al., 1982), so the analysis must be carefully designed to ensure that demographic closure is accounted for in order to select the appropriate model for mark-recapture estimation.

Material and methods

Estimation of Javan rhino population size using mark-recapture calculation requires identification of each individual rhino. Considering the difficulties of physically capturing and marking each rhino, it is agreed that the less invasive method to calculate is through individual identification and differentiating Javan rhinos from photos and/or video. The use of automatic video recording devices (video traps) is an approved method for estimating the population size of the elusive species (Karanth & Nichols, 2002) such as Javan rhino. Therefore, 34 DVREye automatic recording devices were used for this purpose in the peninsula of the Ujung Kulon NP from April 2008 to September 2009. Rhino habitat in Ujung Kulon NP consists of a peninsula of 30,000 ha that is dominated mainly by lowland rainforest, coastal and mangrove forest.

These 34 cameras were systematically placed in the study area and 1 camera was placed in the vicinity of holes at the height of 1.5 to 2.5 metres above ground. These cameras were secured onto a tree with 10 to 20 degree downward angles to record any activity in the wallow hole. Wallow holes were selected using several criteria such as: type of wallow holes (temporary or permanent), the numbers of rhinos known to use a particular hole and the size of the wallow (area in m^2 and the depth of water and mud). Camera placement was mainly focused on permanent wallows that were utilized by one or more rhinos, while the area and depth of the wallow holes were brought in as supporting information used to categorize the wallow types. Selection of wallow holes (camera spots) was made based on a grid system to ensure geographical representation of the rhinos whereby one wallow was selected within each sector of the grid and only one camera was placed at each wallow. Based on rhino movement and home range of 1.4 to 3.8 km per day (Muntasib, 2002), the survey area was divided using grids of 4 km^2 to cover the distance that rhinos travel every day. These grids divided the known rhino habitat of the peninsula into 50 grid squares; 35 out of these 50 grid squares were then selected based on the high rhino occurences recorded in a previous study (Muntasib, 2002; Yahya, 2002). The video trap camera placement locations are shown in Figure. 1.

Based on previous observations of Javan rhino behaviour by Yahya (2002), it is safe to assume that female and male Javan rhinos wallow at approximately the same frequency; thus the camera placements still allow all individuals to have a non-zero probability of capture. This was further assessed by comparing recapture rates of males and females. The survey was conducted within a 10-year period to ensure that the survey covered twice the length of the rhinos' reproductive cycle, as mentioned in Hariyadi et al. (2008). The reproductive cycle was estimated at 3 years with additional 2 years for mother-calf affiliation period; therefore, the period of 10 years should represent 2 repetitions of the reproductive cycle within the population. It is also safe to assume that geographical closure is met, as no rhinos migrated into or out of the rhino habitat during the survey. The camera coverage (sample area) also represents the known rhino home ranges based on Muntasib (2002) and Yahya (2002); thus the areas without known rhino home ranges were not sampled. Since there are no migrations of rhinos into or out of the survey areas, we conclude that migration does not violate the demographic closure set up in the survey design. However, the closure assumption will be tested using

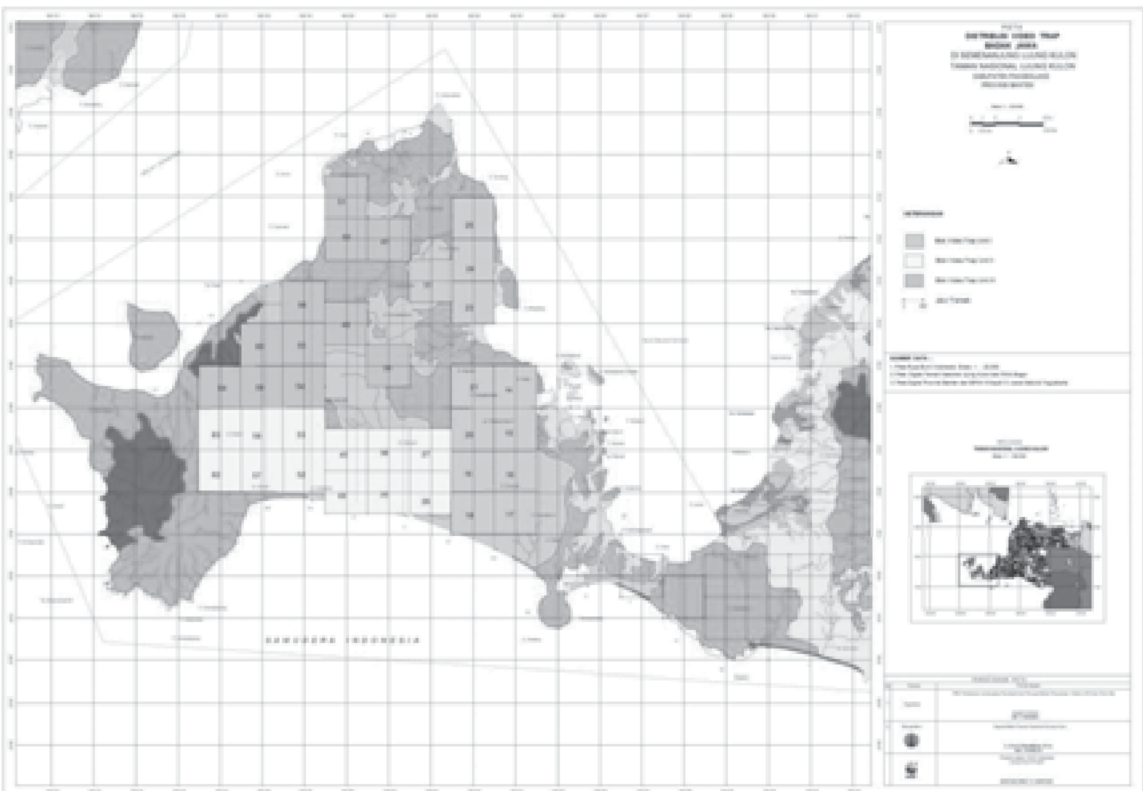

Figure 1. A map of Ujung Kulon peninsula showing the sampling grid representing the known geographic locations of the Javan rhinos.

CAPTURE software (White et al., 1978) to determine the most suitable model for estimating the population of the Javan rhinos.

Each colour represents one of three teams assigned to installing the video trap camera equipment. These video traps were placed to record rhino activities in the selected wallow holes for 15 to 20 days at the same locations. The installment date was marked by assigning a person to walk in front of the camera while holding a signboard containing the date to be recorded, and the camera trap removal/data retrieval date was marked in a similar manner. The period between the installment and data retrieval dates was defined as a survey period. Each of these survey periods represents an ‘occasion’, which is the parameter repeated in the calculation of mark-recapture.

Individual marking and identification were done by observing and comparing morphological features and using parameters developed by Griffith (1993). This method relied on indicators such as: horn shape and size, neck and eye folds, ear shape, footprint size, as well as distinct features (scars, birth marks) to differentiate individual Javan rhinos. At least three parameters must be employed to make a positive differentiation among individual rhinos captured in the photos, while other morphological features (scars, necks, neck folds, etc.) are used for detailed differentiation among individuals found within approximately the same habitat range, or individuals within the same age class or sex. Special attention was given to very young calves travelling with their mothers, as they may indicate recent births. The calves’ ages were estimated using a comparison of body size between the calves and their mothers. Calves estimated at 1 or 1.5 years-old that were not sighted in the previous surveys would be categorized as newborn. All newborn rhinos were tabulated for calculating the birth rate of the population. Examples of the differentiation method are presented in Fig. 2 and 3. Each identified rhino will be given a code according to the sex, age group (calf, subadult, adult), grid number where it was first recorded and a unique individual number to differentiate rhinos that may be detected in the same grid square. With this code, each individual rhino can be recorded, identified and re-identified on different occasion(s). Each video clip with rhino footage was analyzed using a computer capable of running the VLC media player programme, a software that allowed for considerably accurate identification of rhinos based on visual and morphological features mentioned above.

In addition to the individual identification parameters described above, the rhinos were classified into four different age classes based on their overall body and horn size. The first category consists of adult rhinos; both male and female rhinos must have a horn, though that of the male is typically larger. The second category consists of subadults with relatively smaller bodies and horns. The third category represents calves with very small bodies—normally without any distinct horn, and most of their time is spent with their mother.

Analysis was done by identifying, marking (coding) and recording each rhino that was captured on video within the survey period (occasion). Rhino data collection was implemented from April 2008 to September 2009 to ensure demographic closure. In May, June and September 2008, as well as February and April 2009 video trap devices were not operated due to maintenance and repair. Calculation for the Javan rhino population estimate was performed using the Lincoln–Peterson formula and using CAPTURE software (White et al., 1978), which were known to deliver accurate mark-recapture calculations. To comply with the CAPTURE software requirements, rhino detection was represented in a binary system, whereby ‘1’ marks presence and ‘0’ marks absence during each occasion. Data was processed using analysis pattern x-matrix with a statistical population estimation at 95% confidence level. Minimum numbers of rhinos were determined by identifying individual Javan rhinos that were recorded until September 2009.

In order to study the population trend for the past 10 years, results from this year’s analysis were compared to those of 2000, 2004 and 2009, which were analysed in the same manner by WWF and Ujung Kulon NP authorities using the same camera locations from January to December in each year, but using different brands of cameras. This comparison is expected to illustrate the population structure in 2000, 2004 and 2009, as well as describe the differences that may have occurred (differences in age structures and sex ratio that might indicate population dynamics). All births from 2000 and 2009, with the addition of records from 2010, as well as mortality (based on findings of rhino carcasses or remains) were put into a table to calculate the actual population growth of Javan rhino in Ujung Kulon NP. Surveys in 2000, 2004 and 2009 were conducted regularly every month, so birth findings should represent the actual population trend. However, rhino deaths may not reflect the actual mortality rate, as all mortality finds were opportunistic.

Results

Throughout the survey periods, 27 rhinos were identified using CAPTURE (White et al., 1978). Examples of identification and marking of the Javan rhinos are shown in Fig. 2 and 3. These rhinos and their occurrences in each occasion are summarized in Table 1. Recapture rate of females is 0.15 while that of males is 0.17. The calculated closure analysis values (Z=-2.533 and P=0.00565) suggest that the closure assumption is violated. Further calculations for model selection using CAPTURE software's 'Goodness of Fit' models resulted in the 1.00 criteria for $M(_{th})$, suggesting that it is the best suited estimator for mark-recapture, given the capture trend from the dataset. The $M(_{th})$ model calculates a mean estimation of 32 rhinos with a standard error of 4.2381. Further analysis shows that with 95% confidence level it can be ascertained that the Javan rhino population during the survey period of June–September 2009 was between 29 to 47 rhinos. The Lincoln-Peterson formula calculation, using data from the same survey period to enable comparison between the two estimation methods, reveals the mean of 41 individual rhinos with standard error of 19.07, while manual identifica-

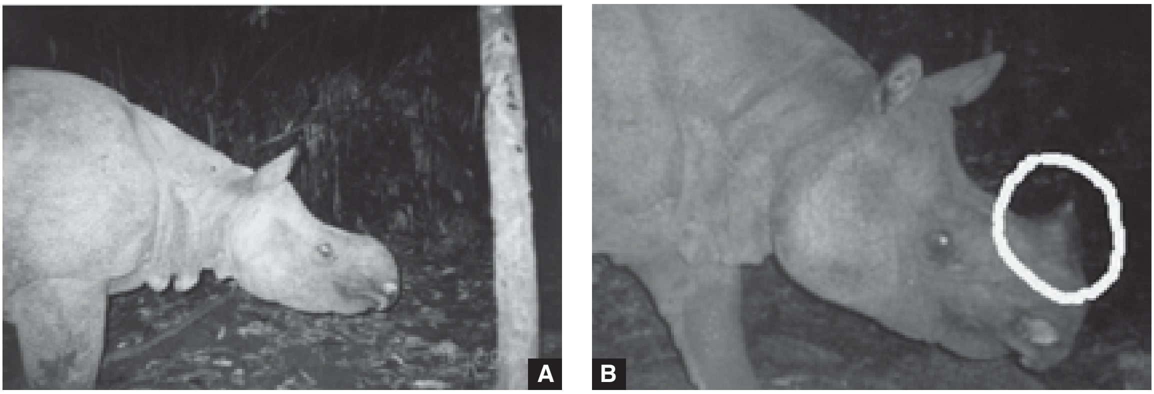

Figure 2. The video capture equipment enabled the team to identify adult rhinos by the presence of the horn in the male (B) and lack of distinctive horn in the female (A). Differentiating sex using horn presence can only be applied for rhinos within the same age class (subadult or adult).

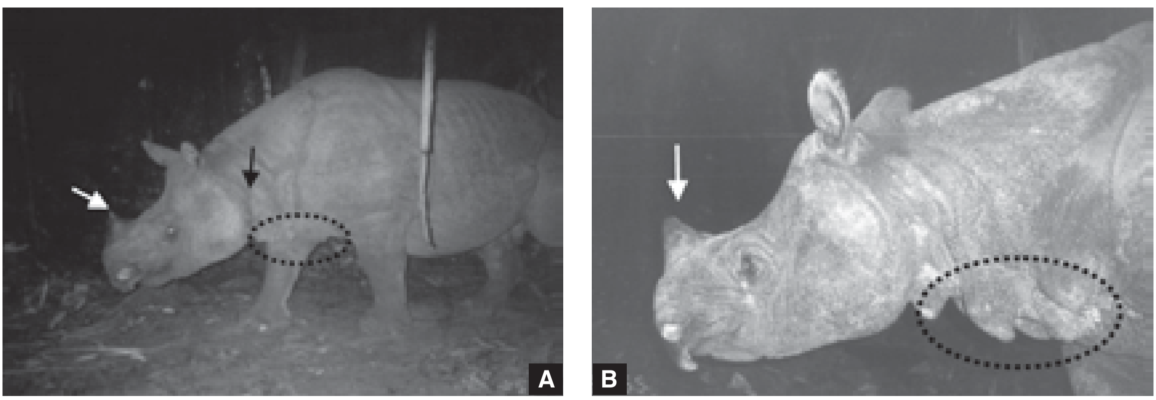

Figure 3. It is possible to differentiate rhinos based on the horn shape as a primary parameter. Note the blunt horn (cone type) on the male rhino in B, while the male in A has a sharper (funnel type) horn tip (white arrows). The rhino in B has a rounded jaw and longer prehensile (upper) lip while the rhino in A has a 'square' jaw as indicated with a black arrow. Male A has continuous neck folds with no skin protrusions, while male B has broken neck folds with conspicuous protrusions downwards from the neck (marked with a dotted oval).

Table 1. Summary of Javan rhinos identified through video trap implementation between April 2008 and September 2009, with observation periods (occasions) represented by the months. Individual detection on each occasion is marked as '1', while no detection is marked as '0'

ID Rhino	Apr	Jul	Aug	Oct	Nov	Dec	Jan	Mar	May	Jun	Jul	Aug	Sept
FADUB1401	0	0	1	1	0	0	0	1	0	1	0	0	0
M,Cal,B14,2	0	0	1	1	0	0	0	1	0	1	0	0	0
FADUB1403	0	0	0	1	0	0	0	0	0	0	0	0	0
FADUB2604	1	0	1	0	0	0	0	0	0	0	0	0	0
MCalB2605	1	0	1	0	0	0	0	0	0	0	0	0	0
FADUB2606	1	1	0	0	0	0	0	0	0	0	0	0	0
FADUB4407	0	0	0	0	0	0	1	1	0	0	0	0	0
FADUB5208	1	0	0	0	0	0	0	0	1	0	0	1	0
MSADB5209	1	0	0	0	0	0	0	0	0	0	0	0	0
MCal B5210	1	0	1	0	1	0	0	0	0	0	0	1	0
FADUB5211	0	0	0	0	1	0	0	0	0	1	0	0	0
MADUB5212	0	0	0	0	0	1	0	0	0	0	1	1	0
MADUB5513	0	0	0	0	0	1	0	0	0	0	1	0	0
FADUB5614	0	0	0	0	0	0	0	1	0	0	0	0	0
MCal B5615	0	0	0	0	0	0	0	1	0	0	0	0	0
MADUB3516	0	0	0	0	0	0	0	1	0	1	1	0	1
MADUB2117	0	0	0	0	0	0	0	1	0	1	1	0	0
MSADB2018	0	0	0	0	0	0	0	0	0	1	0	0	0
MADUB3519	0	0	0	0	0	0	0	0	0	1	1	0	0
MADUB3520	0	0	0	0	0	0	0	0	0	0	1	0	0
MCalB5221	0	0	0	0	1	0	0	0	0	0	1	0	0
FADUB4522	0	0	0	0	0	0	0	0	0	0	0	0	1
MADUB5723	0	0	0	0	0	0	0	0	0	0	0	0	1
MADUB5024	0	0	0	0	0	0	0	0	0	0	0	1	0
FSAB1725	0	0	0	0	0	0	0	0	0	0	1	0	0
FADUB1726	0	0	0	0	0	0	0	0	0	0	1	1	1
MCalB1727	0	0	0	0	0	0	0	0	0	0	1	1	1

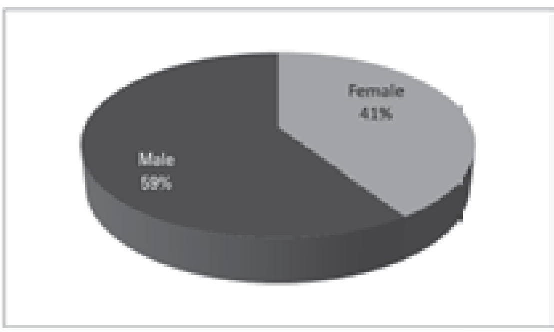

Figure 4. Pie chart showing the composition of males and females in the Javan rhino population surveyed between April 2008 to June 2009.

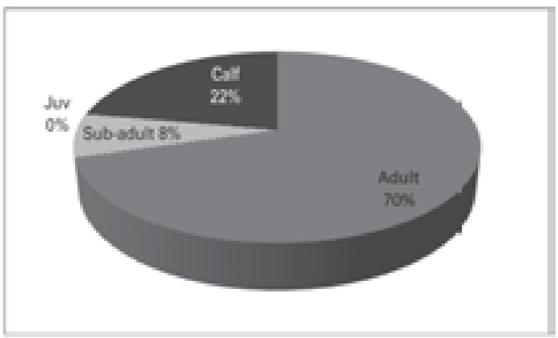

Figure 5. The age structure of Javan rhinos in the peninsula of Ujung Kulon NP surveyed from April 2008 to July 2009. The large percentage of calves indicates th e breeding capability of this population.

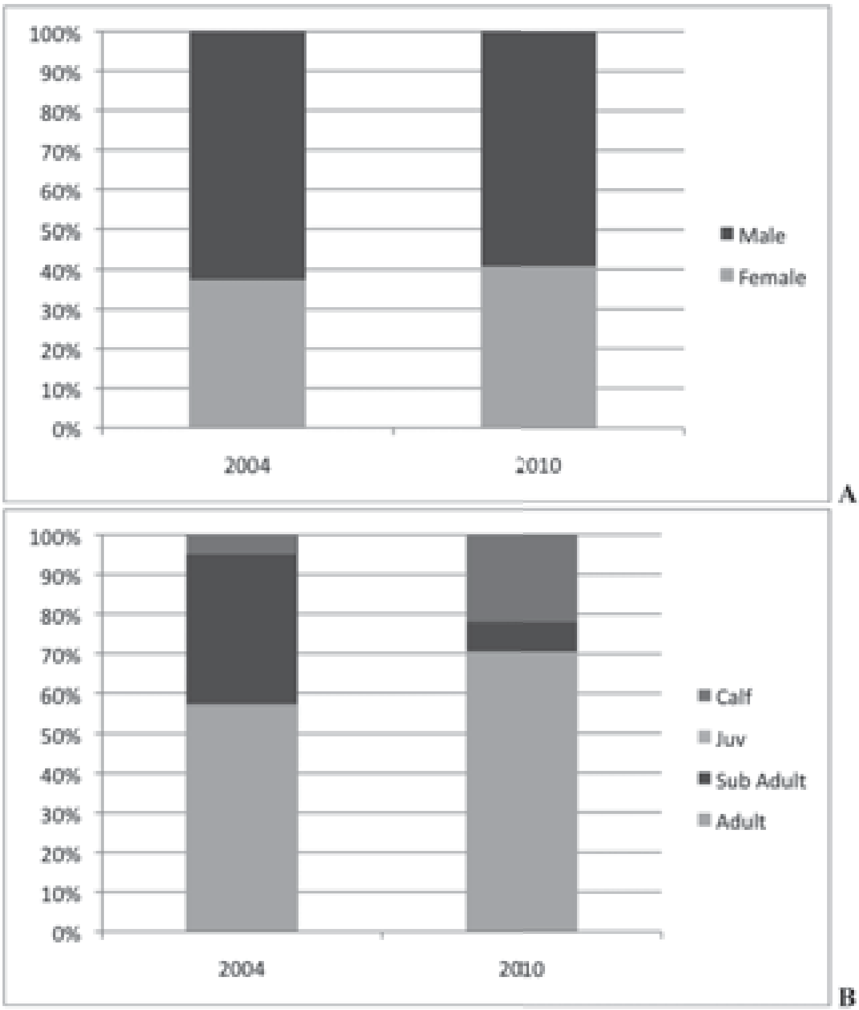

Figure 6. Comparison of Javan rhino's sex ratio (A) and age composition (B). The sex ratio recorded in 2004 and 2010 is consistent, while there is an increase of of adults and calves from 2004 to 2009.

Table 2. Compilation of birth findings recorded from camera/video trap implementations from 2000 to 2010 with mortality based on carcass findings throughout the period

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Birth			2		3		4		3	2	
Mortality		1	1	1	1		1	1			3

tion from video footage yields 27 individual rhinos.

There were a total of 11 females and 16 male rhinos identified from video capture, resulting in a female to male sex ratio of 2:6 (41% females and 59% males), as shown in Fig. 4, while there are 18 adults, 3 subadults and 6 calves as shown in Fig. 5.

This result (2009) is compared with the results from 2004 to study the population dynamics and show the population composition over time (Fig. 6). The comparison shows that the sex ratio does not differ

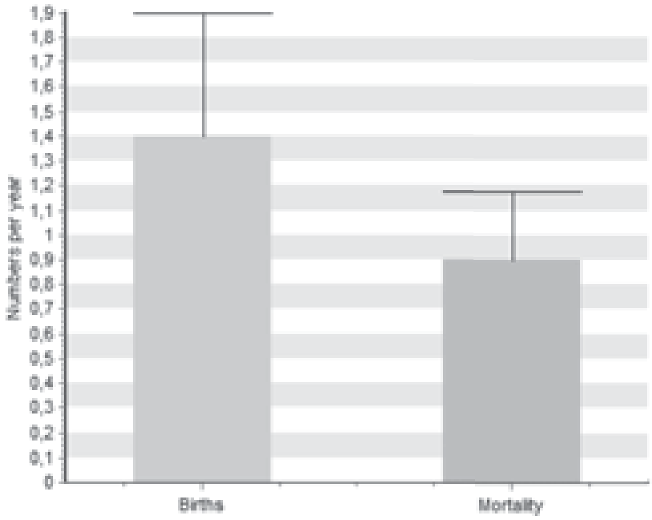

Figure 7. Comparison of average birth and mortality of Javan rhino from 2000 through 2010.

much between 2004 and 2009, but there is a difference in the age structure of the population between these periods of observation.

In order to study the population trend based on birth rate (derived from camera trap and video trap identifications) and mortality rate (based on finding of carcasses and remains etc.), all data from 2000 to 2009 were compiled and shown in Table 2. Based on this data, the average birth rate is 1.4 births per year (Standard Deviation: 1.5776), and the average mortality rate is 0.9 deaths per year (Standard Deviation: 0.8755) (Fig. 7).

Discussion

Estimating the population of the Javan rhino using the mark-recapture technique can be applied as an option that is less invasive and possibly more discriminative than the existing footprint count method. However, this method relies on the accuracy of identification and differentiation of individual rhinos as a prerequisite. Detection of false positives will yield an inaccurate estimation from the CAPTURE software, so photos of individuals that cannot be identified cannot be used for such analysis. Both the Lincoln-Peterson formula and CAPTURE software will only yield accurate results based on the accurate identification of rhinos from photos and videos. Three-way identification (identification made and agreed by three persons) is considered as a valid evaluation procedure.

Similar recapture rates of females and males (0.15 and 0.17 respectively) suggest that sex bias using camera observation due to differences in wallow frequencies between male and female is negligible. When comparing the results from CAPTURE and Lincoln-Peterson, it is noted that there are differences in standard error values that may be attributed to the accuracy of each formula. CAPTURE produces a mean population estimate at 32 rhinos with Standard Error 4.2381, while calculation using Lincoln-Peterson formula produces a mean estimation of 41 rhinos with standard error 19.07. The smallest standard error is produced from the use of CAPTURE software, which suggests a modest uncertainity in the population estimate compared to the Lincoln-Peterson formula. Based on the above calculations, and manual identification from rhino photos, it can be concluded that with a 95% degree of confidence that the rhino population on the peninsula of Ujung Kulon NP during the period of April 2008 to September 2009 was between 29 and 47 rhinos. Closure test suggests that the closure assumption is violated. This may be true due to the births and mortalities of rhinos throughout the survey period causing the demographic closure to be violated; however, the geographic closure is met during the surveys. Furthermore, violation to the closure assumption is common when a survey is carried out over a long period of time where there is also a possibility of time dependent wallowing behaviour due to the reduction of wallow holes in the dry season.

In comparing the identification results on the age structure between 2004 and 2009 it is clear that although the sex ratios do not differ between the two periods, the age structures do differ. The differences in age structure may be attributed to the growth of 2004's subadult individuals into adult individuals in 2010, thus indicating a shift towards an adult-biased population. However, the increase in the percentage of calves indicates that this population is still capable of producing offspring, although almost all of the 2009 newborns are males, which pushed the sex ratio to male-dominated.

Descriptive analysis in comparing the birth and mortality rates from 2000 to 2010 shows a net population growth of five rhinos within the 10-year period (0.5 net growth per year or approximately

1% population growth). Although not significant, and still much lower than the targeted 3% annual population growth (PHKA, 2007), the population might potentially be growing. However, the mortality recorded in 2010 (three deaths) is relatively higher than average, so further investigation on the cause of death in 2010 is necessary. Since poaching has been stopped, other causes of death of adult rhinos will need to be carefully examined. The possibility of disease must not be overlooked. This should enable population managers to prevent an increase of the mortality rate within these populations in the future. In addition to studying the cause of mortality, such as diseases and other abnormalities, the stagnant population for the past 10 years suggests that the carrying capacity of the Ujung Kulon peninsula may have been reached. Therefore, future efforts to save the Javan rhino must include: improving the existing habitat quality (increasing food plant quality and abundance), locating sites outside the current geographical distribution to be designated as a second habitat, and the translocation of individual rhinos to the second habitat to start a new population. Having another population of Javan rhinos outside their current distribution in Ujung Kulon NP will greatly increase the chance of survival of this species.

Conclusions

Implementation of camera/video trap surveys appear to be a good method for monitoring Javan rhino population in Ujung Kulon NP, as it enables identification of individual rhinos. Accurate identification is a prerequisite in using mark-recapture analysis, as the identification serves marking of individual specimens. Judging from the standard error produced from using CAPTURE program and Lincoln-Peterson estimation for mark-recapture it can be concluded that the former yields lower uncertainity in the estimation, as it produces a much smaller standard error than the latter. Based on this long-term study to monitor the population of Javan rhinos (*Rhinoceros sondaicus*) in Ujung Kulon NP, the rhino population size is estimated at a minimum of 29 and a maximum of 47 individuals. Despite the male-biased sex ratio the population is capable of reproduction, but due to the the mortality rate the net population growth is only 0.5 individual per year (which corresponds to 1% population growth per year between the years 2000 and 2010). In order to achieve the target of 3% net growth of the Javan rhino population, the birth rate needs to increase and, importantly, the mortality rate needs to be reduced.

Acknowledgements

The research is made possible in co-operation with Ujung Kulon NP Authority, Indonesian Ministry of Forestry, WWF, International Rhino Foundation (IRF), Asian Rhino Project (ARP), and WWF-AREAS (Asian Rhino and Elephant Action Strategy). Also thanks to Abishek, Stephan Wulfraat and Arnaud Lyet for the valuable input on the statistical and editorial aspects of mark-recapture estimation.

References

Griffiths, M. (1993). *The Javan Rhino of Ujung Kulon An Investigation Of Its Population And Ecology Through Camera Trapping*. Indonesia: WWF.

Hariyadi, A.R.S., Santoso, A., Setiawan, R. and Priambudi, A. (2008). 'Automatic Camera Survey for Monitoring Reproductive Pattern and Behaviour of Javan Rhinoceros (*Rhinoceros sondaicus*) in Ujung Kulon National Park, Indonesia'. *Proceeding of the 3rd International Meeting on Asian Zoo/Wildlife Medicine and Conservation* (AZWMC).

Hariyadi, A.R.S., Setiawan, R., Daryan, Y.A. and Purnama, H. (2010). 'Preliminary behaviour observation of the Javan Rhinoceros (*Rhinoceros sondaicus*) Based on Camera Trap Surveys in Ujung Kulon National Park'. *Pachyderm* 47:93–99.

Hoogerwerf, A. (1970). *Udjung Kulon the land of the last Rhinoceros*. Leiden: EJ Brill.

Karanth, K.U. and Nichols, J.D. (2002). *Monitoring Tigers and Their Prey: A Manual for Researchers, Managers, and Conservationists in Tropical Asia*. Bangalore, India: Centre for Wildlife Studies.

Lewis, J.C. (1970). 'Wildlife Census Method: A résumé'. *Journal of Wildlife Diseases*. 6:356–364.

Mackenzie, D.I. and Royle, J.A. (2005). 'Designing occupancy studies: general advice and allocating survey efforts'. *Journal of Applied Ecology* 42:1105–114.

Munson, L., Koehler, J.W., Wilkinson, J.E. and Miller, R.E. (1998). 'Vesicular and Ulcerative Dermatopathy resembling Superficial Necrotic Dermatitis in Captive Black Rhinoceroses (*Diceros bicornis*)'. *Vet Pathol* 35:31–42.

Muntasib, E.K.S.H. (2002). *Penggunaan Ruang Habitat Oleh Badak Jawa (*Rhinoceros sondaicus*, Desm 1822) Di Taman Nasional Ujung Kulon*. Disertasi Fakultas Kehutanan Institut Pertanian Bogor (IPB).

PHKA (2007). *Strategy and Action Plan for the Conservaion of Rhinos in Indonesia 2007-2017*. Republic of Indonesia: Ministry of Forestry,

Sajudin, H.R. (1984). *Studi Perilaku dan Populasi Badak Jawa (*Rhinoceros sondaicus *Desmarest 1822) di Ujung Kulon*. Tesis Fakultas Biologi Universitas Nasional.

Schenkel, R., Schenkel-Hullinger, L. and Ramono, W.S. (1969). 'Area management for the Javan rhinoceros (*Rhinoceros sondaicus* Desm.), A Pilot study'. *The Malayan Nat. J.* 31:253–275.

Schenkel, R. and Schenkel-Hullinger, L. (1969). The Javan rhinoceros in Ujung Kulon Nature Reserve: its ecology and behavior. *Acta Tropica* 26:98–135.

Shadwick, R.E., Russel, A.P. and Lauff, R.F. (1992). 'The Structure and Mechanical Designs of Rhinoceros'. Dermal Armor. *Phil. Trans. R.Soc. London* 337:419–428.

Setiawan, R. and Yahya, A. (2002). *Studi Populasi dan Distribusi Badak Jawa (*Rhinoceros sondaicus*, Demarest, 1822) Melalui Perhitungan Koleksi Feses dan Tapak di Taman Nasional Ujung Kulon*. Balai Taman Nasional Ujung Kulon & WWF Indonesia Project ID0091.07.

Talbot, L.M. and Stewart, D.R.M. (1964). 'First Wildlife Census of the Entire Serengeti-Mara region, East Africa'. *The Journal of Wildlife Management* 28(4):815–827.

White, G.C., Anderson, D.R., Burnham, K.P. and Otis, D.L. (1978). *User's Manual for Program Capture*. Logan Utah: Utah State University Press.

White, G.C., Anderson, D.R., Burnham, K.P. and Otis, D.L. (1982). *Capture-Recapture and Removal Methods for Sampling Closed Population*. Los Alamos New Mexico: Los Alamos National Laboratory.

Yahya, A. (2002). *Studi Populasi Badak Jawa (*Rhinoceros sondaicus*) Melalui Kamera Penjebak Infra Merah Di Taman Nasional Ujung Kulon*. Indonesia: WWF.