The Sumatran rhinoceros in Way Kambas National Park, Indonesia: a study of a population exposed to catastrophic events.

Philip Wells

The Sumatran rhinoceros in Way Kambas National Park, Indonesia: a study of a population exposed to catastrophic events.

PHILIP WELLS

Summary

1. The Way Kambas National Park holds one of the 13 known populations of the critically endangered and cryptic Sumatran rhinoceros (*Dicerorhinus sumatrensis*). The park suffered severe drought and forest fires in 1997 as a result of the El Niño Southern Oscillation. The abundance of other species in the park was known to have been reduced but the effect on the rhino population was unknown.
2. As part of an ecological study of the Sumatran tiger (*Panthera tigris sumatrae*) camera traps were operated in 29 locations from 1995 up to the present which also successfully photographed Sumatran rhino 130 times. Independently rhino protection units collected field observations on rhino sign found within the park.
3. The rhino photographs were analysed to identify the minimum number of rhino and the density of rhino was calculated using an effective sampling area of the camera traps. The total population within the park was estimated by extrapolation using the distribution of rhino inferred by the rhino sign collected by the rhino protection teams. An annual index of relative abundance was also calculated using number of photographic events per unit effort.
4. From 93 independent photographic events ten adult Sumatran rhinos and one calf were identified from the photographs. In the period up to and including 1997 (pre-El Niño) the rhino population was estimated to be 20 to 33 individuals with an estimated carrying capacity of 60 individuals. After the El Niño event the population was estimated to be 7 to 16 individuals, a reduction of at least 50 percent. The annual index of relative abundance also showed a reduction of between 54 to 87 percent in the period immediately following the El Niño event.
5. Even in the absence of rhino poaching in the park climatic events were found to lead to catastrophic reductions in the rhino population.

Key-words: Sumatran rhinoceros, camera trap, El Niño.

Introduction

The Sumatran rhinoceros (*Dicerorhinus sumatrensis*, Fischer 1814) is a solitary cryptic rainforest dwelling browser that naturally lives at low densities (Strien 1986). The species in the wild is rarely seen making any study relying on direct observation impossible. Previous population and ecological studies of the Sumatran rhino have used indirect signs such as footprints (Reilly *et al.* 1997, Wells *et al.*1994, van Strien 1986, Flynn & Abdullah 1984, Borner 1979). The advent of relatively cheap remote operated cameras has provided an alternative methodology.

The Sumatran rhino is classified as critically endangered (IUCN 2002). The world population of Sumatran rhino has under gone a 50 percent decline in the 1980's and 1990's mainly due to poaching for their horn (Foose & Strien 1997) with only an estimated 208 to 320 individuals in 13 isolated locations remaining in the wild (Foose & Strien 1998).

The Sumatran rhino in the 1970's was believed to have become locally extinct in Way Kambas National Park (Borner 1979, Wind *et al.* 1979). The area of what has now become the national park was intensively logged between 1954 and 1974 (Franklin 2003) and was subjected to illegal hunting including the Sumatran rhino (Wind *et al.* 1979, N. Franklin pers. comm.). In 1993 the Sumatran rhino was 'rediscovered' (Reilly *et al.* 1997) and the population was estimated to be approximately 30 individuals (Foose & Strien 1998). In response to the existence of Sumatran rhino in the park the Indonesian Rhino Conservation Program (IRCP) deployed three rhino protection units (RPU's) in 1998 whose function was to protect and collect field data on the Sumatran rhino (Wells 2000). The collected field data has been used in this study to establish the distribution of the Sumatran rhino within the park.

In 1997 the entire Indonesian archipelago suffered from serious draughts associated with the El Niño Southern Oscillation (El Niño) resulting in an unprecedented fire episode where more than nine million hectares of land were burnt (Stolle & Tomich 1999). At least 17 of Indonesia's national parks were affected (Kinnaird & O'Brian 1998) including the Way Kambas National Park. During the latter half of 1997 in

Way Kambas National Park the drought led to a majority of water sources to dry up or become saline due to the ingress of seawater and the wildfires affected 63 percent of the park (Franklin 2003). In the areas affected by fire the number of tree saplings, the primary food source of the Sumatran rhino, was found to have been significantly reduced (Franklin 2003). Franklin (2003) also found that despite little direct evidence of mortalities the abundance of Sumatran tiger (*Panthera tigris sumatrae*) and their prey species were negatively affected in the years following the El Niño event. The effect on the population of Sumatran rhino in the park was not known although there was evidence of disruption to the population due to the finding of rhino sign outside the area they would normally be found (Wells 2000).

In 1995 the Sumatran Tiger Program (STP) established a study site in the park using remote camera traps to investigate the ecology, status, and distribution of the Sumatran tiger (Franklin *et al.* 1999). In the latter part of 1995 a Sumatran rhino was photographed by a camera trap (Siswomartono *et al.* 1996). Since that date a total of 130 photographs of Sumatran rhino have been collected within the park. This data has been used in this study to establish a minimum number of Sumatran rhino in the park.

Photographic techniques have been used previously to study cryptic species by identifying individual animals within a population such as rhino and tiger (Franklin 2003, Franklin *et al.* 1999, Poleti *et al.* 1999, Karanth & Nichols 1998, Karanth 1995, Griffiths 1994, Griffiths 1993, Dinerstien 1991). They have also been used to investigate periods of activity (Lizcano & Cavelier 2000, Schaik & Griffiths 1996, Griffiths 1993, Griffiths & Schaik 1993) and as a measure of relative abundance (Kinnaird *et al.* 2003, Carbone *et al.* 2001).

The identification of rhino from photographs when using remote camera techniques is considered difficult due to the lack of obvious identifying features unlike the unique patterns of stripes on individual tigers. In a previous study of the Javan rhino (*Rhinoceros sondaicus*) individuals have been identified using various morphological features (Griffiths 1993). With the absence of distinctive skin texture and plates the Sumatran rhino is generally considered more featureless than the Javan rhino.

The hypothesis central to this study is that individual adult Sumatran rhino can be distinguished from one another by morphological features which will be demonstrated. From the photographs collected by STP a minimum number of rhino and an estimated population density will be established and the data collected by the RPU's will be used to describe the rhino distribution and hence the estimated total population within the park. The combined data sets will be analysed with respect to the 1997 El Niño event to examine what impact the drought and fires have had on the rhino population.

Materials and Methods

STUDY AREA

Way Kambas National Park in the province of Lampung is situated on the south eastern end of the island of Sumatra in the Indonesian archipelago (4°37′ to 5°16′ S; 105°33′ to 105°54′ E). The park is almost entirely flat with an elevation of 0-60 metres a.s.l. typical of the eastern coastal plains of Sumatra. It is bounded by the Java Sea to the east and the remaining areas a bounded by intensive agriculture separated to the north, east and southeast by rivers (Fig. 1.). The eastern side of the park includes large areas of swamp including mangroves (*Avicenia marina, Rhizophora spp.*) and nippa (*Nypa fruticans*). The western side of the park is dominated by grasslands (*Imperata cylindrical*) and scrub. The more central areas are covered by lowland tropical forest with some open grass swamps. The western edges of the forest tend to be more open without a closed canopy. In this study the vegetation map has been created using a 1996 Landsat® image. The vegetation types were broadly classified as grassland, scrub, open forest, closed forest, open swamps and closed swamps. The vegetation map has been integrated into a GIS map (geographic information system) of the park created from digitising 1:50,000 topographical maps using MapInfo®.

CAMERA TRAPPING

Infrared beam activated camera traps (TRAILMASTER® TR-1500) were situated at 29 locations optimised to capture tigers and their prey as described in Franklin (2003) and Franklin *et al.* (1999). When an animal passes in between the infrared transmitter and receiver the camera is automatically activated and the time and date is registered in the data logger. All cameras were programmed to operate 24 hours per day for between seven and ten days when the film and battery were changed. A small time delay was programmed to prevent unnecessary repetitious photographs. The exact location of all cameras was noted using a global positioning system (GPS) entered into the GIS map (Fig. 1.). The cameras were operational from August 1995 to September 2000 producing a combined total of 13,297 camera days, and since that date some have been operated by the Way Kambas National Park staff on a more informal basis. The initial period up to the end of 1995 was considered by Franklin (2003) as a trial period over which the camera systems were tested to find the optimal methods. Photographs of rhino taken in the initial period and post September 2000 have been included in the rhino identification process but excluded from analyses relating to trapping effort. Any series photographs of the same individual taken within a six hour period at the same location were considered a single photographic event

SURVEY DATA

The RPU's have conducted fulltime operations in the park since 1998 routinely collecting data on rhino during all their foot patrols. They are experienced and fully trained trackers able to differentiate between signs made by rhino and those made from other species (Wells 2000). All direct sightings and secondary sign including prints, dung, active wallows and feeding sign are noted in standard patrol reports with the position established using a handheld GPS. A data base of all rhino sign and other observations including illegal activities is maintained.

FEATURES USED TO IDENTIFY INDIVIDUALS

The horn, sex, skin folds, facial wrinkles, ears, hoof pigmentation, and other wrinkles were used variously to identify individual rhinos. The photographs were sorted in a systematic manner using these features to allocate as many photographs as possible to individuals.

The two horns are the most obvious feature of a Sumatran rhino. The horns of a rhino will grow throughout its life, and be worn down at a rate depending on the characteristics of an individual rhino's behaviour, and the mechanical properties of the horn itself. The resulting size and shape of horns from these processes is believed to be relatively stable over time for adult rhino. The size and morphology of horns were found to be highly variable in the photographic collection. The profile shape of the anterior horn can be broadly described as being alternatively: double convex (bullet shaped), convexo concaved (sabre shaped), or high convexo concaved (classic). The posterior horn was significantly smaller in all cases and sometimes appearing absent altogether in profile. The posterior horn was described alternatively: absent, square, triangular, and cylindrical. The bilateral symmetry of the horn when viewed in profile facilitated in matching right handed and left handed pictures of the same animal. It was however hard to determine the true shape of the horn when viewed from the front.

From captive Sumatran rhinos it can be seen that morphologically there is little difference between males and females although males will be generally larger. Positive identification of the sex of an animal can only be obtained from direct observation of the genitalia, or in the case of a female if a calf is accompanying it. When pictures are taken of a male from the side the penal sheath can be seen protruding from the rear if the nearside hind leg is in the forward position. For a female photographed in a similar position the absence of a penal sheath can enable the sex to be determined even if the genitalia are not visible.

The skin of rhino is relatively inelastic (Shadwick *et al.* 1992). Additional flexibility is obtained in a similar manner to a concertina via skin folds especially in the neck and the upper front legs where good mobility is required. The size and shape of the folds changes depending on the position of the head and legs. However, consistent patterns made by the folds can be found between photographs of the same individual when the posture of the rhino is the same. As the position of the head relative to the body during locomotion tends to be relatively the same, the neck folds were more commonly used to identify individuals. In the neck there are three main folds: primary (from behind the ear down to the throat latch), secondary (starting from the upper shoulder and behind the ear forming a collar hanging under the neck often in the form of a Y when seen from the side), and tertiary (starting from the chest and lower shoulder to the mid neck). The secondary fold is the most visible and voluminous with the lower part of the Y shape sometimes coiling in on itself. The silhouette of the shape of the neck folds hanging under the neck are a bilateral feature in a similar manner to the horns.

Each rhino has a unique pattern of facial wrinkles predominantly around the eyes but also running from the mouth and nostril towards the eye and up from the eye towards the ear. The visibility of different wrinkles was found to be strongly dependant on the clarity of the photograph and the lighting conditions. It was however felt to be the most constant feature as the patterns were independent of posture and orientation of the head relative to the camera.

There was some variation found in the shape of the ears and the hairs on the inner side and outer edge of the ear that could be used as diagnostic features. The colour of the hooves tended to vary between black, dark grey and brown and was subject to lighting conditions. However, some rhino appeared to have consistently lighter or darker coloured hooves. More importantly the inner hooves of the front and hind legs sometimes had light coloured pigmentations that formed distinctive patterns that could be used as an identifying feature.

Other wrinkles on the body could be used to support identification of individuals especially in the region of the flank and buttocks. The visibility and position of the wrinkles were found to vary with posture and the orientation of the camera but in a number of cases was useful.

THE PROCESS OF IDENTIFICATION

The use of morphometric analysis was considered as a means of identifying rhino from the photographs. However any picture of sufficient quality for which reliable measurements could be taken were rare and readily identifiable making the technique redundant. The photographs were examined and sorted into groups with consistent identifying features. The horn of the Sumatran rhino being its most obvious feature was used to initially sort the photographs into groups using general horn shapes. Each group was further examined to look for consistent and inconsistent features as a basis to subdivide the group. This process was continued exhaustively until a large number of groups existed. The majority of these groups consisted mainly of photographs taken of the left or right side of an animal. These left and right handed groups were combined via a linking photograph when an individual had turned or partially turned during a photographic series, or by the bilateral features such as the horn and neck fold profiles.

The groups were considered to represent individual animals when they were found to be consistent within themselves and positively distinguishable from all other groups. Within the remaining photographs that could not be assigned to individuals a picture appearing to be of a previously unidentified individual, but could not be positively excluded as being one of the identified rhino, was treated as a 'possible individual'.

The photographs were examined without reference to spatial and temporal information with the exception of those series within a single photographic event. Only after the all the groups of photographs of the individuals had been finalised were the locations of each photograph plotted. Any photograph within a group which had a position inconsistent with the others of that group was re-examined.

A plot of the cumulative number of identified rhino against cumulative effort should be in the form of a logistic curve if all rhino present in the sampling area have been detected under conditions of demographic closure. Sumatran rhino have an inter-calf interval of at least 3 years and do not reach maturity until about 7 years (Strien 1986) so if only adult rhino are considered then the assumption of demographic closure can be used for periods of up to 3 years. The cumulative numbers of identified adult rhino were plotted independently for the period from 1996 to 1997 and for the period 1998 to 2000 and tested by visual inspection.

HOME RANGES AND CORE AREAS

The home ranges of rhino is defined as the total area a rhino may utilise, and core area is defined as the area a rhino would normally be found within. The home range and core area was calculated for only one individual as the remainder were photographed too infrequently (<10 times) and/or at only three or less locations. A minimum convex polygon (MCP) was thought to be an inappropriate means of estimating the home range and core areas as their outer extremities cannot be determined, and do not take into account the frequency of observations at the different cameras. The Kernel method of estimating home ranges (Worton 1989) offers an alternative means of determining home ranges and core areas. The method uses a non-parametric statistical procedure to calculate probabilities of an animal being in various locations in two-dimensional space, without making prior assumptions of the probability distribution. A 90% Kernel was used to describe the home range (90% probability of being found within the area) and 60% Kernel was used to describe the core area. The locations of the animal was imported into ArcView® and the home range and core areas were calculated using the Animal Movement Extension® (developed by the US Geological Survey) with a least squares cross validation method of smoothing.

EFFECTIVE SAMPLING AREA AND POPULATION DENSITY

In order to calculate the density of rhino it is necessary to estimate the effective sampling area of the camera traps. It is usual to define effective sampling area as a MCP surrounding the trap locations with an additional buffer to take into account the animals that live in part outside the MCP (Franklin 2003, Karanth & Nichols 1998, White *et al.*. 1982). However this does assume that the spatial distribution of the cameras is sufficient to capture all animals within the area bounded by the MCP and they are set appropriately to capture the target species. In this case the camera locations were optimised to capture pictures of tigers and their prey and not to capture rhinos with six out of the 29 traps classified as being located in open areas which Sumatran rhino would not normally be expected to be found. Other factors may also affect the success of a trap for rhino such as a lack of 'topographic compression' (Griffiths 1993) where natural obstacles and features or well established game trails will lead the rhino into a camera trap. In this paper it is assumed that only those camera traps that over the course of the entire study photographed a rhino were indeed appropriately located. The union of a buffer surrounding all successful camera traps was used to estimate the effective sampling area therefore not requiring the assumption of sufficient camera coverage. The width of a buffer used in previous studies of tigers (Franklin 2003, Karanth & Nichols 1998) has been calculated on an *ad hoc* basis as the half the mean maximum distance moved for animals trapped on more than one occasion and is repeated here. In addition the expected radius (3.09 km) of a male home range (30 km^2) (Strien 1986) is also used as a buffer width to estimate the sampling area. The male home range is larger than the female so this is expected to provide a conservative estimate of rhino density.

The population density was calculated by using the minimum number of identified rhino within the effective sampling area. Upper and lower estimates were created using the different effective areas with or without the inclusion of possible individuals beyond the minimum known individuals.

RHINO DISTRIBUTION AND POPULATION ESTIMATE

To establish the rhino distribution within the park the data base of observations of all rhino sign collected by the RPU's was entered into the GIS map separately for each year of operations from 1998 to 2001. The amount of effort (kilometres walked and hours spent) collecting the data for each part of the park is not known. The RPU's do concentrate their efforts on the areas of the park that have rhino as well as those where illegal activities are known or suspected to have occurred. The distribution of the rhino sign was compared to all observations including other mammal species and illegal activities to ensure that the entire park has been covered. An inferred rhino distribution was estimated from the distribution and number of observations taking into account the different vegetation types. The distribution was classified as a core and peripheral areas. The core rhino area is the area in which the rhinos will spend a majority of their time and the peripheral areas are those which may at times be utilised or visited by the rhino (c.f. individual rhino home range and core area). The population densities calculated were applied to the core rhino area to provide estimates for the number of rhino in the entire park.

PHOTOGRAPHIC RATES AND RELATIVE ABUNDANCE

Carbone *et al.* (2001) found a good correlation between photographic capture rates of tigers and their density between different studies with varying methodologies and terrain. The author (unpublished data) has shown that the number of photographs per unit effort can be predicted using a mathematical random walk model for a given population density, mean distance travelled per day, and the effective area of a trap. The number of photographic events including identified and unidentified rhino per unit effort was calculated for each of the years 1996 to 2000 as an index of relative abundance using all camera traps and only those that successfully photographed a rhino. Mini-max approach was used to estimate of the range in the percentage reduction of rhino numbers using maximum and minimum values of the index of relative abundance pre and post El Niño and *vice versa*.

DAILY ACTIVITY

The number of photographs taken for each hour of the day was counted to establish the parts of the day when rhino were most active. The difference between nocturnal and diurnal activity was tested for significance using the non-parametric Mann-Whitney U Test. Each hour of the day was assigned to either day or night with the period of dawn being assigned to day and the period of dusk being assigned to night.

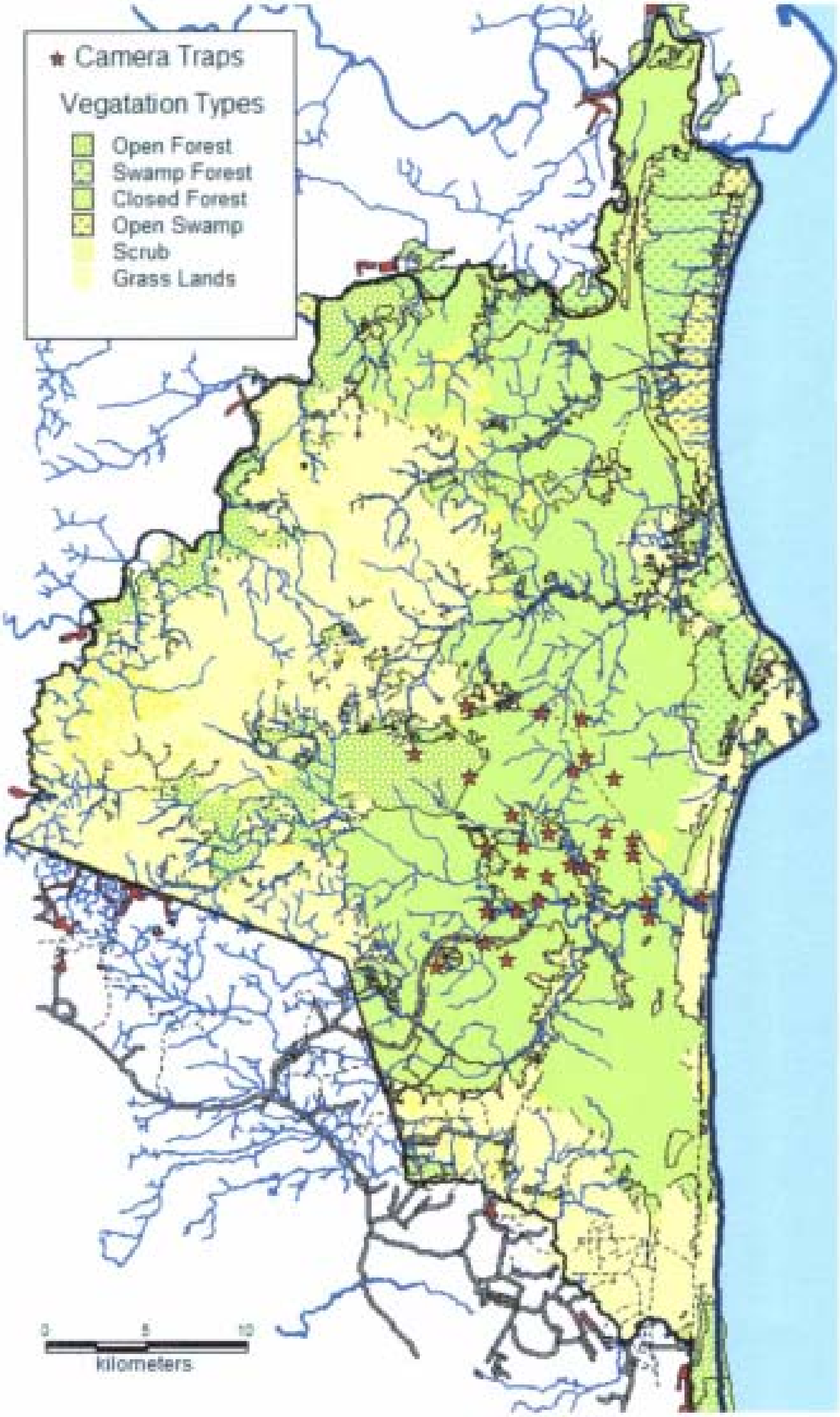


Fig. 1. Vegetation map of Way Kambas National Park. The vegetation cover was mapped from a 1996 Landsat® image. The park is bounded to the east by the Java Sea and to the west by intensive agriculture separated by rivers to the north, northwest and southwest. The eastern edge of the park is predominantly swamp; the western side is mainly grass lands. Centrally forested area is closed forest with more open forest on its western edges. The location of the camera traps are indicated by the red stars.

Results

IDENTIFICATION OF INDIVIDUALS

A total of ten adult rhino and one calf were identified (Table 1) from a total of 130 photographs constituting 93 independent photographic events between 1995 and 2002. A total of 26 photographic events could not be positively included as being one of the eleven individual rhinos. Nine of the adults were photographed prior and/or during the 1997 El Niño event of which only three were re-photographed after this date. A new individual U3 was photographed once post El Niño in July 2000. The male rhino M1 was photographed significantly more times (n = 29) and more locations (n = 9) than any other rhino. Of the ten adults four were found to be male, three female, and three of unknown sex.

The location of the photographs for each individual was examined using the GIS map (Fig. 2.). All those photographs of an individual whose position appeared inconsistent were re-inspected to ensure that the correct identification had been made. None of those photographs was found to be incorrectly identified.

Table 1. List of the eleven rhinos identified between 1995 and 2002. Of the nine adults photographed before the end of 1997 only three were photographed post 1997. A new individual U3 was photographed once in July 2000.

Name	Sex	Age	Number of Photo Events	First Photo	Last Photo	No. of locations	Survived post 1997
M1	male	adult	29	17/04/1996	10/02/2002	9	yes
M2	male	adult	3	20/05/1996	18/09/1996	1	?
M3	male	adult	8	27/01/1997	04/08/1999	3	yes
M4	male	adult	8	19/06/1996	15/10/1997	3	?
F1	female	adult	5	07/11/1997	30/11/1997	1	?
F2	female	adult	4	10/09/1996	19/10/1996	2	?
F3	female	adult	3	05/10/1995	19/06/1997	3	?
U1	unknown	adult	3	17/11/1997	21/02/1998	2	yes
U2	unknown	adult	2	25/12/1996	16/08/1997	2	?
U3	unknown	adult	1	22/07/2000	22/07/2000	1	yes
J1	unknown	calf	2	09/11/1997	04/12/1997	1	?

Within the 29 photographs that remained unidentified it is thought possible that there are three as yet not positively identified individuals but could not be positively excluded as being the same those already identified due to lack of clarity or photographic angle. Two of the possible individuals were photographed during the 1997 El Niño event (an adult and a sub-adult) but not re-photographed afterwards, and one was photographed once in 2000.

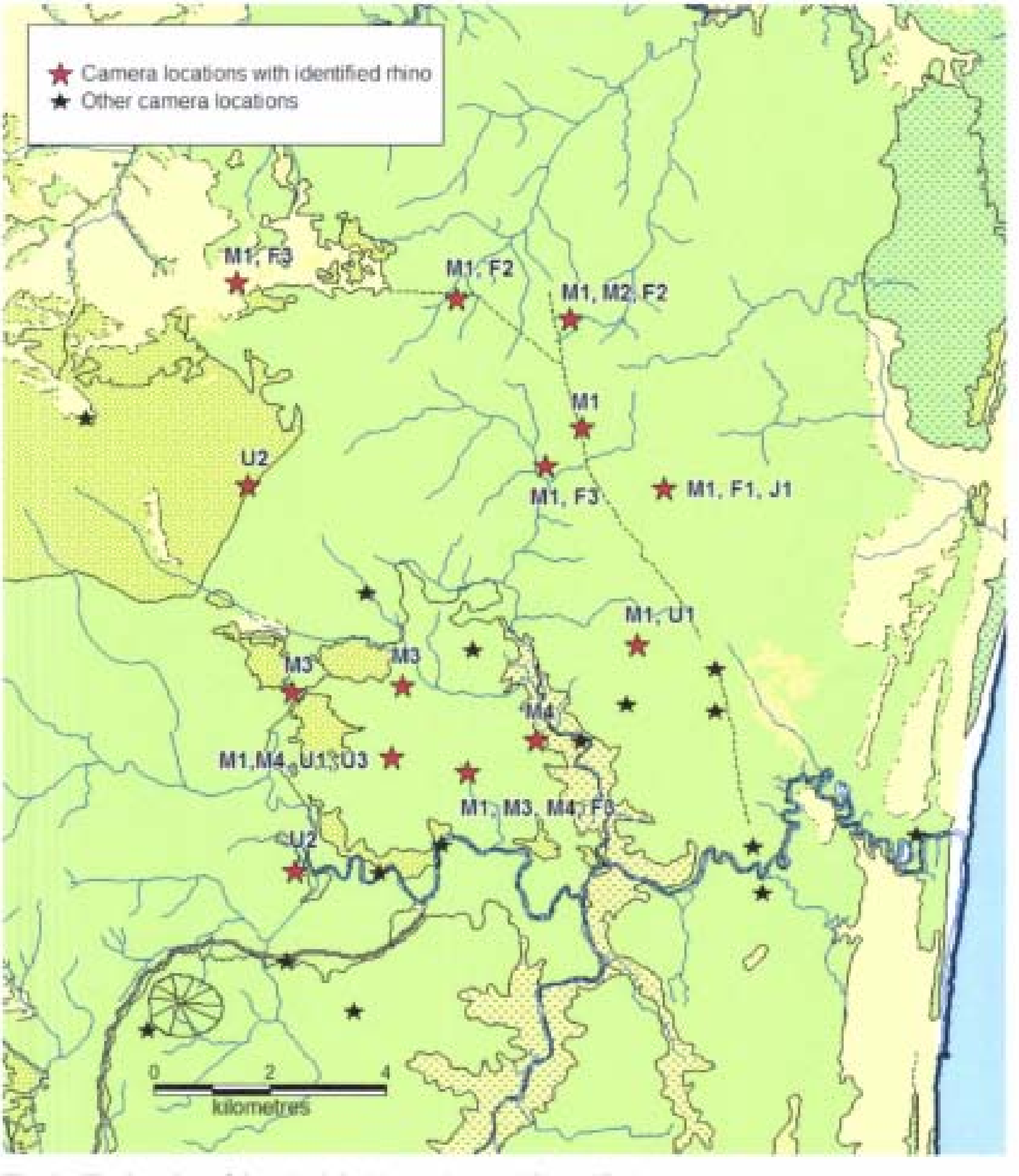
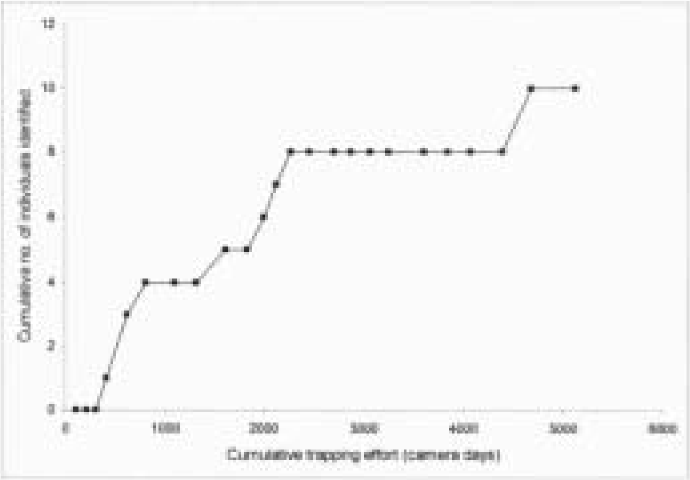
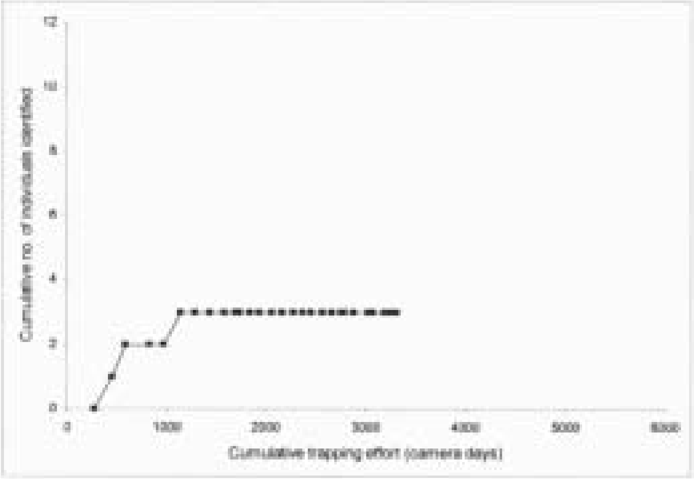


Fig. 2. The location of the 10 adult rhino and one calf identified. The stars indicate the location of all camera traps, with the ones coloured red indicating traps that had photographed identified rhino.

The cumulative number of adult individuals identified was plotted against the cumulative trapping effort (camera days) for the period 1996 to the end of 1997 (pre-El Niño) and for the period 1998 to 2000 (post-El Niño) (Fig. 3). For the pre-El Niño period the shape of the curve has the appearance of being logistic in shape with the exception of two individuals identified for the first time during the climax of the draught and forest fires. The curve for the post-El Niño period is logistic in form which would be expected if all individuals had been identified.



a.



b.

Fig. 3. The cumulative number of adult individuals identified plotted against cumulative trapping effort for **a.** pre-El Niño and **b.** post-El Niño. Both graphs appear logistic in form except at the end of the pre-El Niño period suggesting that all rhino that exist in the sampling area have been photographed.

CONSISTENCY OF IDENTIFYING FEATURES

The shape and size of the horns of the rhino identified were found not to change over time for the adult rhino. The horns of M1 best illustrate the case as the rhino was photographed over the longest period. The horns of M1 are shown in Fig. 4 with a time interval of 57 months and are compared to two other male rhino M2 and M3 which can be seen to be easily distinguishable. Only 28 of the 93 photographic events (30%) could the sex be directly determined of the animal photographed and one case due to an adult female being accompanied by a calf.

The skin folds of the upper leg and neck were found to be consistent for M1 over the period it was photographed. The differences in skin folds between individuals are demonstrated in Fig. 5 between M3 and M4. M3 had a very large and distinctive primary neck fold that allowed the animal to be easily identified. The facial wrinkles were also found to be consistent over time and unique to all individuals, Fig. 6 clearly demonstrates the point with comparisons made between M1 and U1.

The shape of the hoof pigmentations on the inner hooves when clearly visible proved to be vital in making a positive identification in a small number of cases. However, it is inconclusive whether the patterns of hoof pigmentations are permanent or whether they vary over time as all photographs in which pigmentations were clearly visible were taken only months apart.

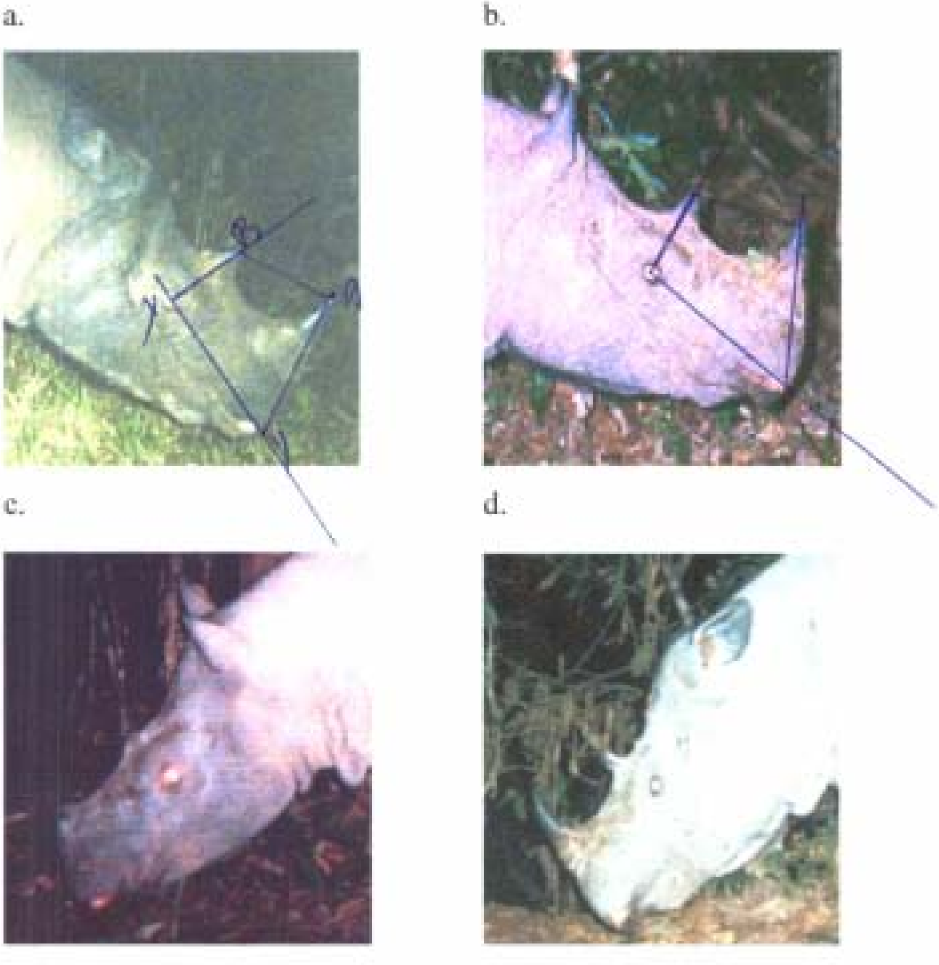


Fig. 4. The horns of three different male rhino. The male M1 is shown photographed in **a.** and **b.** (separated by a period of 57 months), M2 is shown in **c.** and M3 in **d.**. The relative size and shape of M1's horn are shown to remain constant over time and distinctly different from the horns of M2 that are small and rounded. M3 has superficially similar horns to M1 but the anterior horn is more curved and the posterior horn lacks the distinctive triangular shape of M1.

Fig. 5. Comparative photographs of upper leg and neck skin folds of two individuals M4 **a.** & **b.**, and M3 **c.** & **d.**. In the photographs of M4 the Y shaped secondary neck fold is seen although less clearly visible in **b.** as the animals head is turning away from the camera stretching the neck but the general shapes of the folds of the neck and upper leg are maintained. M3 has a distinctive primary neck fold that makes the animal readily identifiable.

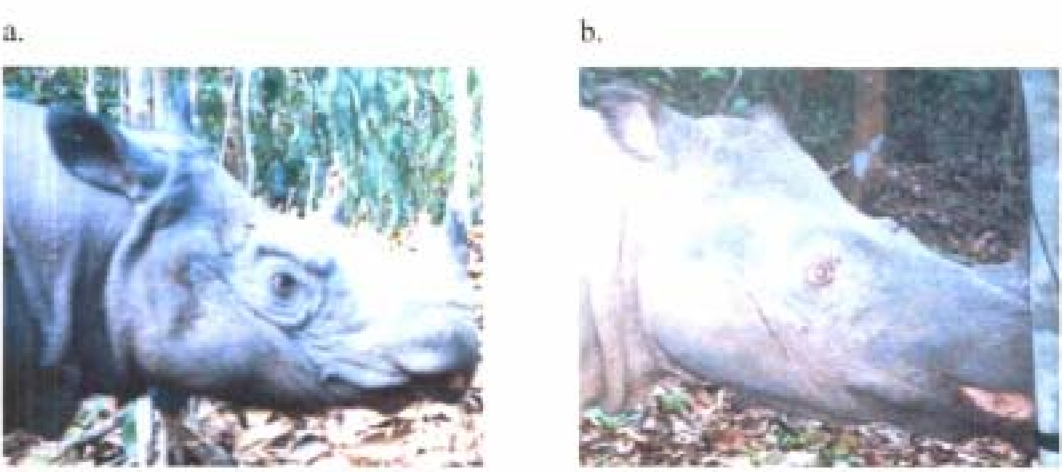


Fig. 6. Comparison of facial wrinkles between **a.** M1 and **b.** M2. Good quality pictures are required to clearly see the facial wrinkles but each animal was found to have unique patterns around the eye and the more lateral wrinkles running from the nostril and mouth towards the ear.

HOME RANGES AND CORE AREAS

Only one rhino (M1) was photographed often enough (n = 29) and at a sufficient number of locations (n = 9) to warrant estimating the home range and core area. M1 was found to have its core area in the north-eastern corner of the sampling area, but it also made infrequent visits to the central area. As it was photographed only five times after the El Niño event it is not possible to judge whether there has been any shift in it core area or home range. The core area was found to be 30.1 km^2 (60% Kernel), home range 96.9 km^2 (90% Kernel), and a MCP bounding all the locations it was found to be an area of 41.2 km^2 (Fig. 7). On one occasion M1 was photographed at the most western southern point during the day and that night re-photographed at its most eastern point that are separated by a Euclidian distance of 6.6 km.

EFFECTIVE SAMPLING AREA AND POPULATION DENSITY

The number of photographs per 100 camera days for every camera trap was calculated for the period 1996 to the end of 1997 (pre-El Niño) and the traps were classified as being in either an open area or closed forest as per Franklin (2003). The number of photographs per 100 camera days for open areas (n = 6, mean = 0.3468, s = 0.7748) and closed forest (n = 21, mean = 1.0278, s = 1.322) were tested with a One-Way ANOVA and found not to be significantly different ($F_{1,25} = 1.424$, $P = 0.244$).

The maximum Euclidian distance between locations of photographs taken for each adult rhino was calculated (n = 10, mean = 3.795 km, s = 3.65). A buffer within the primary rhino habitat was created using the half of the mean maximum distance (pre-El Niño 89 km^2; post-El Niño 84 km^2), and the expected radius of a male Sumatran rhino (144 km^2; 142 km^2) (Fig. 8). This gave a density range of 6.23 to 12.35 rhinos per 100 km^2 pre-El Niño and 2.83 to 5.97 rhino per 100 km^2 post-El Niño (Table 2).

Table 2. Estimates of rhino density in the primary rhino habitat pre and post El Niño. The number of rhino and the estimated effective sampling area are used to calculate the density. The minimum number of rhino identified within the period and the minimum number plus the possible rhino provide a range of estimates. The effective sampling area is calculated using a buffer around the successful camera traps using both the half mean maximum distance moved for rhino and the radius of an expected male home range.

Pre-El Niño	1/2 Mean Maximum Distance	Male Home Range
Buffer width (km)	1.898	3.09
Effective trapping area (km^2)	89.07	144.4
Density with min. no. of rhino per 100 km^2 (nine rhino)	10.10	6.23
Density with max. no. of rhino per 100 km^2 (eleven rhino)	12.35	7.62

Post-El Niño	1/2 Mean Maximum Distance	Male Home Range
Buffer width (km)	1.898	3.09
Effective trapping area (km^2)	83.81	141.5
Density with min. no. of rhino per 100 km^2 (four rhino)	4.77	2.83
Density with min. no. of rhino per 100 km^2 (five rhino)	5.97	3.53

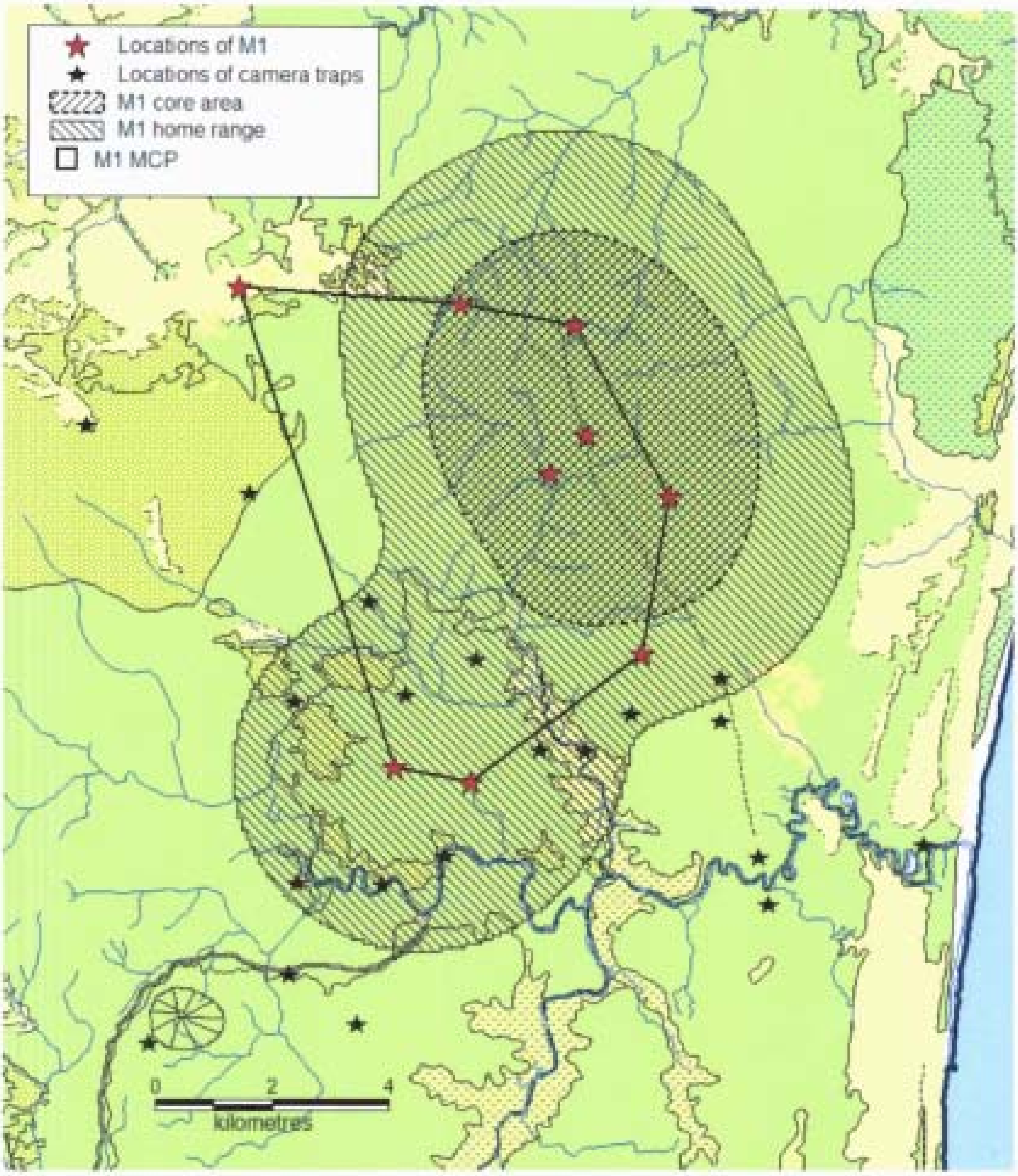


Fig. 7. The home range, core area, and MCP of rhino M1. The home range (96.9 km^2) and core area (30.1 km^2) of the male M1 were calculated using a 90 and 60 percent Kernel respectively. The MCP was 41.2 km^2. The locations where M1 was photographed are indicated as a red star.

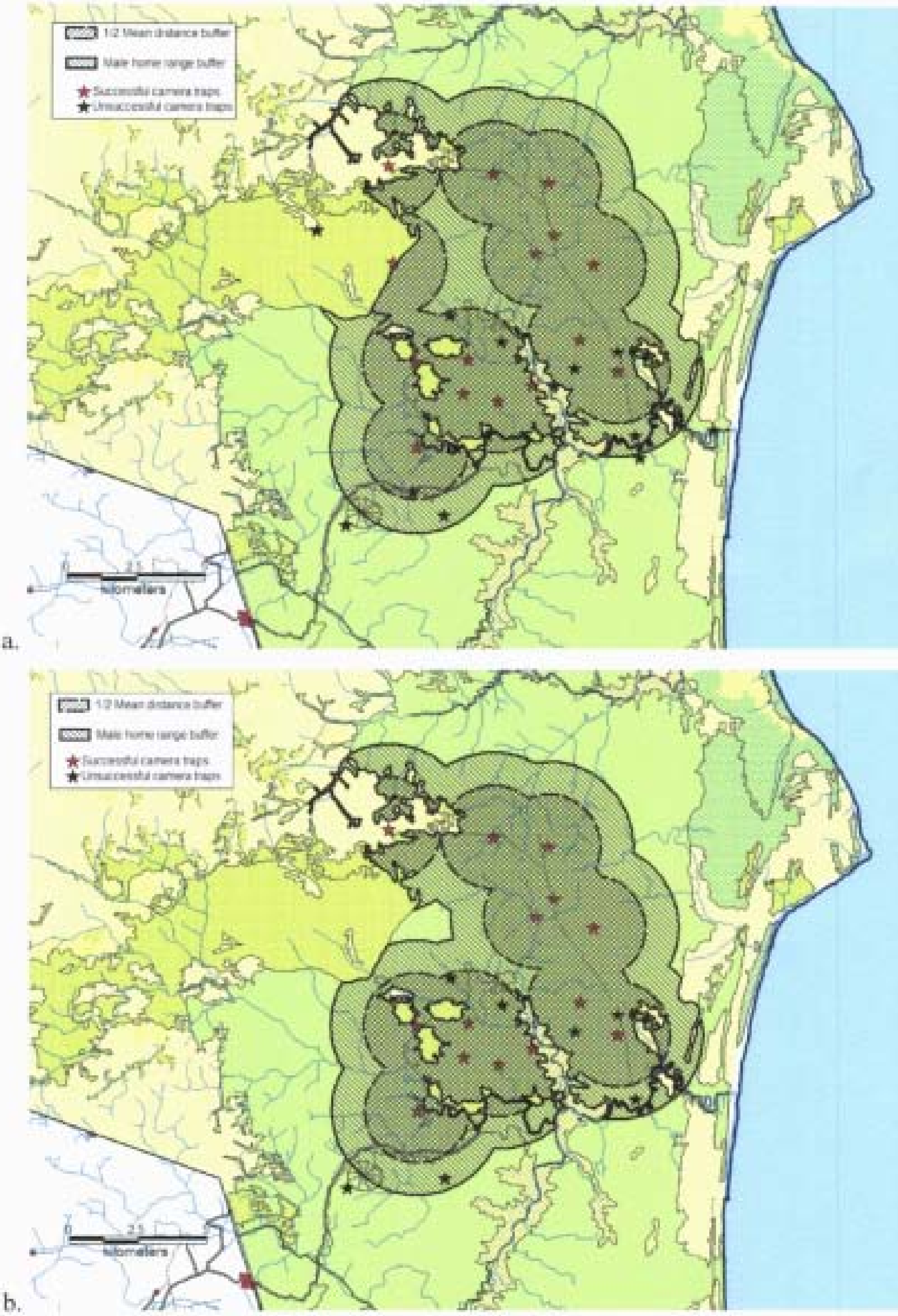


Fig. 8. Buffers indicating the effective sample area of the successful camera traps for a. pre-El Niño, and b. post-El Niño. The region filled with diagonal lines with a solid outline has a width of the radius of a male home range (3.09 km). The region filled with a crosshatch and a stippled outline has a width of half the mean maximum distance between photographs for all rhino (c.f. Franklin 2003, Karanth & Nichols 1998). The red stars represent successful camera traps and the black stars indicate unsuccessful camera traps.

RHINO DISTRIBUTION AND POPULATION ESTIMATE

The distribution of rhino sign found by the RPU's for the years 1998, 2000, and 2001 (Fig. 9) was found to be consistently concentrated in the central forested area bounded by the Wako River to the north and the Kalibatin River to the south designated the core area. The areas adjacent to the core area in which sign was occasionally found was designated the peripheral rhino area (Fig. 10). The number of observations outside the core area in 1998 was the largest and this number decreased during the following years.

The distribution of all RPU observations including other species and illegal activities demonstrates that all areas of the park have been covered except the swamps with an apparent bias of effort within the core rhino area (Fig. 9). The core area was found to be 264 km^2, 49 percent of available closed forest. Using the calculated densities of rhino over the core area, the total population for the park was calculated to be within the range of 20-33 rhino pre-El Niño and 7-16 rhino post-El Niño event, indicating an approximate 50 percent reduction in rhino numbers.

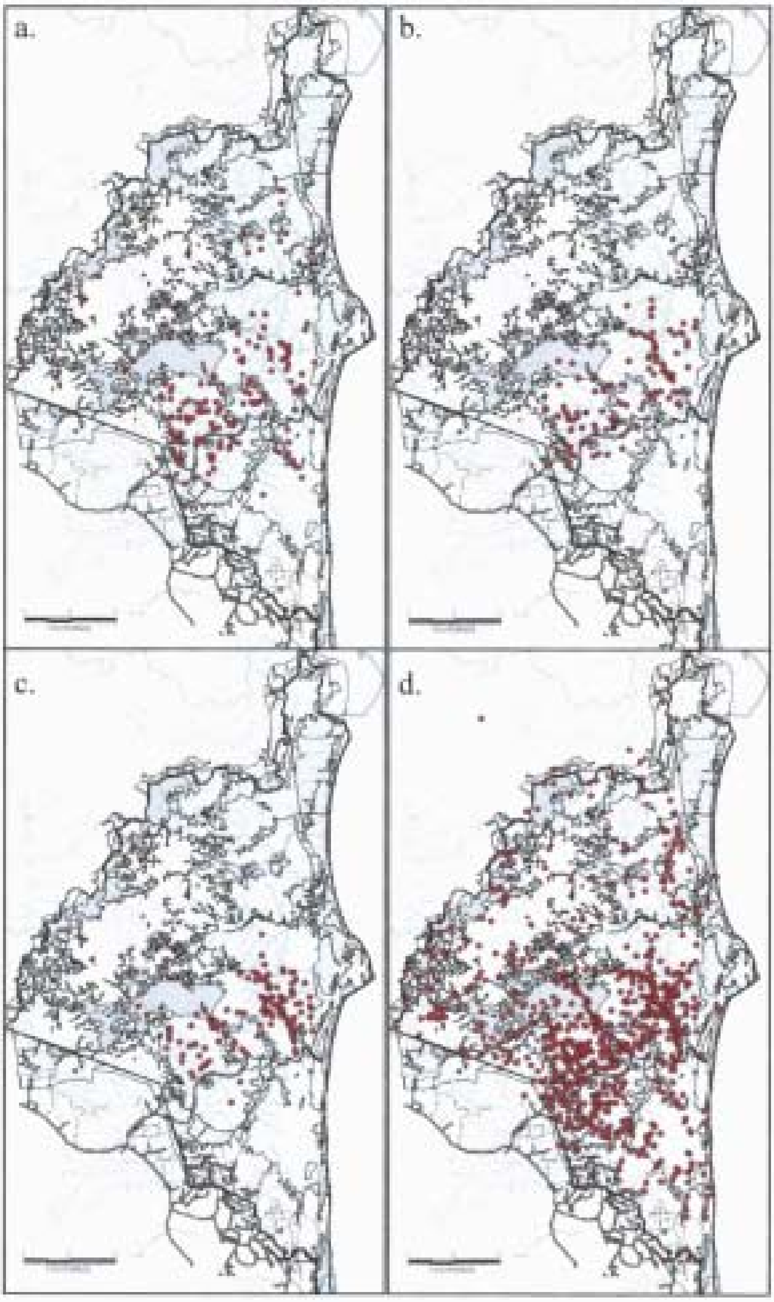


Fig. 9. Maps showing the distribution of rhino sign found by the RPU's **a.** 1998 **b.** 2000 and **c.** 2001. The distribution of all observations including other species is shown in **d.** which demonstrates that the RPU's have patrolled the entire park except the swamp areas.

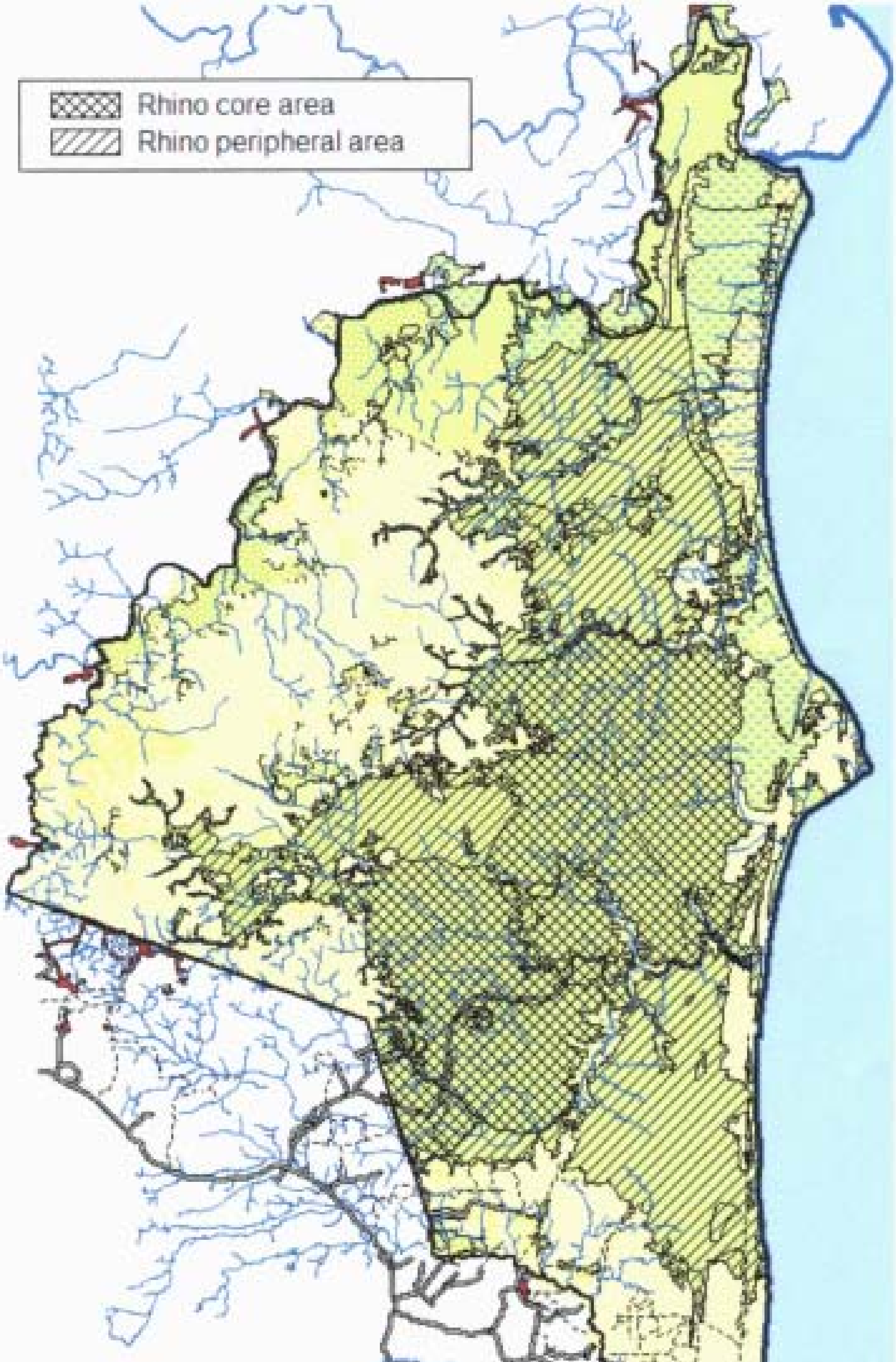


Fig. 10. Map of the rhino core (cross hatched) and peripheral (striped) areas. The core area represents the area were rhino sign are consistently found all of which is closed forest. The peripheral areas are areas where rhino sign is occasionally found and may be closed or open forest.

PHOTOGRAPHIC RATES AND RELATIVE ABUNDANCE

The annual index of relative abundance for the years 1996 to 2000 shows a marked reduction post-El Niño (Fig. 11). The mini-max approach for all traps and only successful traps indicate a maximum reduction of between 87-77 percent and a minimum reduction of 54-55 percent (Table 3). The minimum reduction is in close agreement with the reduction in the estimated rhino densities calculated from the identification of individuals.

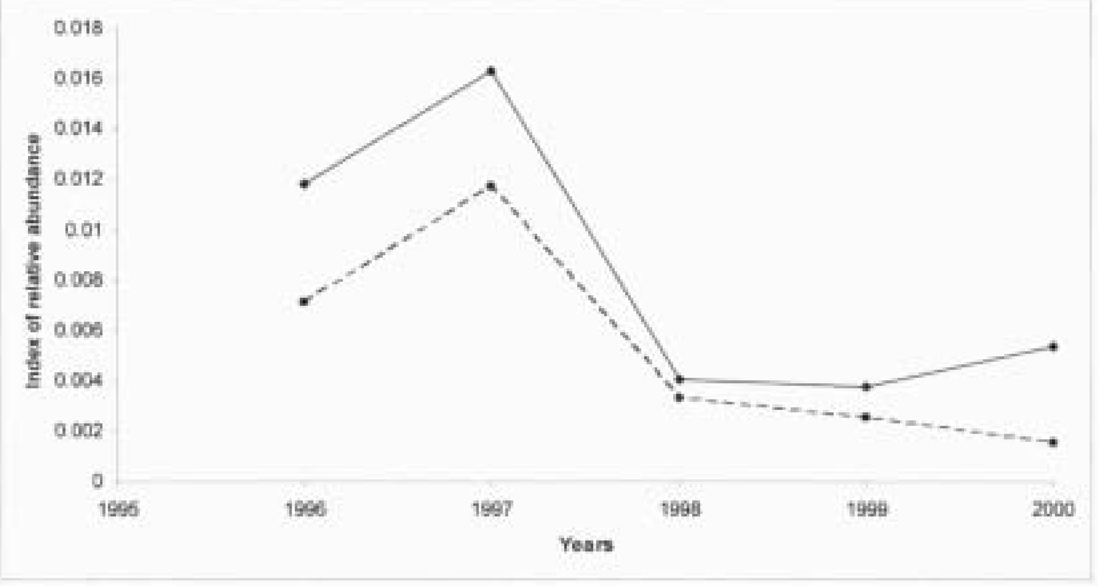


Fig. 11. Graph showing the index of relative abundance of rhino from 1996 to 2000. The index of relative abundance was calculated from the number of photographic events divided by the camera trap days. The diamonds and solid line represent the density index calculated from only those traps that ever caught a rhino, and the dashed line represents a density index calculated from all traps. The graph indicates a large drop in the rhino density after the 1997 El Niño event.

Table 3. The maximum and minimum decline in the rhino populations estimated from the index of relative abundance for **a.** all traps and **b.** only successful traps.

	a. Density index all traps		b. Density index using successful traps	
	Maximum	Minimum	Maximum	Minimum
1996-1997	0.012	0.007	0.016	0.012
1998-2000	0.003	0.002	0.005	0.004
Max. decline		87%		77%
Min. decline		54%		55%

DAILY ACTIVITY

The number of photographic events for each hour of the day was counted (Fig. 12). The mean ranks of the counts during the day and night hours were compared using the Mann-Whitney U test and found to be highly significantly different ($Z = -2.639$, $P = 0.008$) with the majority of activity being between dusk and midnight.

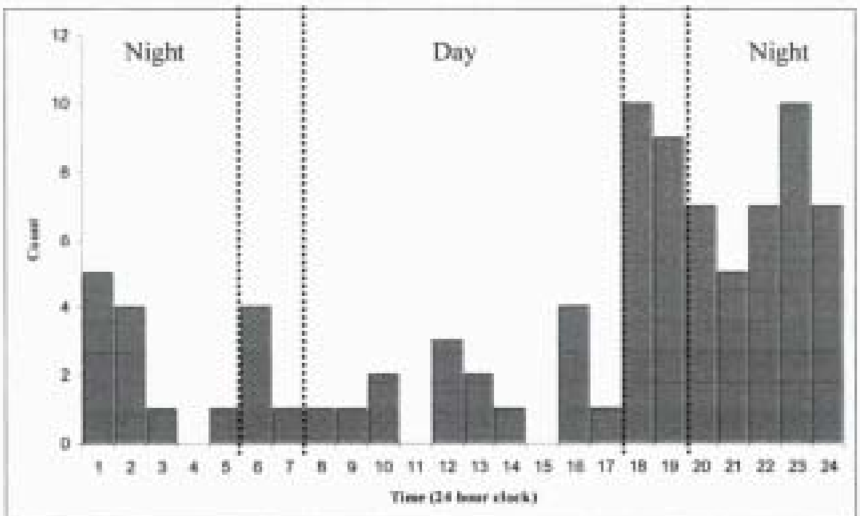


Fig 12. The number of photographic events counted for each hour of the day. The number of photographic events at night was found to be significantly greater than during the day.

Discussion

The photographing of the Sumatran rhinos was a rare event with only 93 independent photographic events recorded over an excess of 13,500 camera days. Franklin (2003) over the a similar period 1996 to 2000 recorded 435 photographic events of Sumatran tigers which in turn was small relative to a number of other species such as 2,104 photographs of muntjak (*Muntiacus muntjak*). Ten adult rhino and one calf could be identified from 67 of the 93 photographic events using the techniques described. The large amount of effort expended to obtain these photographs may appear prohibitive if the sole purpose was to catalogue the rhinos present in the sample area. However, prior to the 1997 El Niño event 80 percent of the individuals had been photographed within 2,500 camera days (Fig. 3). This could be reduced further if the camera traps were set to specifically capture rhino rather than tiger and their prey as in this case. Also once a catalogue of sufficient numbers of photographs has been collected the amount of annual effort could be reduced further such that the continued presence of individuals can be monitored. The amount of effort required using camera traps is probably comparable to other methods such as identifying rhino from plaster casts of foot prints, but photographs are considerably quicker to analyse (Strien 1986; 700 field days over 6 years, and 2000 hours of analysis).

The process of making an estimate of the number of rhino in the Way Kambas National Park is subject to a number of unquantifiable errors. The range of the estimates only gives an indication of the expected error (pre-El Niño 20-33; post-El Niño 7-16). The groups of photographs of identified rhino were exclusive, but 26 of the 93 photographic events that could not be assigned to individuals may include other rhino, and inspection of the unassigned photographs suggests that there were at least three more possible rhino. However, the logistic form of the cumulative total of rhino plotted independently in the periods before and after 1997 against the cumulative effort suggests all the rhino had been identified, with the exception of towards the end of the first period when two more rhino were photographed (Fig. 3). These two rhino may have been forced by the drought and forest fires into the sampling area where they would not normally be found. The number of rhino therefore could be under or overestimated.

The effective sampling area is another potential source of error. The half mean maximum distance had a large standard deviation, and the radius of an expected male home range from an ecologically distinct region of Sumatra used to estimate the sampling area was questionable. The core area of the home range of the rhino M1 (30.1 km^2) was, however, consistent with the conservative home range estimated by van Strien (1986) using MCP's which he noted may be as large as 50 to 60 km^2 similar to the MCP of M1 (41.2 km^2), but less than the 96.9 km^2 estimated using the 90 percent Kernel. If the home ranges and core areas of a number of rhino could be established then there would be greater certainty that the buffer used to create the effective sampling area was appropriate.

The maximum pre-El Niño population density of 12.35 rhino per 100 km^2 is comparable with the estimated 13-14 rhino per 100 km^2 of an undisturbed rhino population (Strien 1986). No rhino poaching has been recorded in the park since 1961; however this high density would have required a rapid recovery of the remnant population in the 1970's.

The distribution of rhino sign found by the RPU's is relatively discrete covering 49 percent of available habitat. There is an autocorrelation in the density distribution of the rhino sign found by the RPU's as they concentrate their efforts in the areas that contain rhino but this should only strengthen the contrast between core and peripheral areas (Fig. 9). The distribution of all observations shows that the whole area of the park has been covered except the areas of coastal swamps during the course of law enforcement patrols. This indicates that all the areas that contain rhino have been recorded (Fig. 9d).

In 1998 some rhino sign were found at the extreme western edge of the park in sub-optimal habitat about 14 km from the core area, which during part of 1997 was adjacent to the only drinkable water in the park (Fig.9a). Rhino were never previously found in this area and have never been observed since. This is strong evidence that the severe drought and forest fires in 1997 caused a large disruption to rhino population. Also the number of rhino sign in the peripheral areas was greatest in 1998 and declined in the years following suggesting the disruption caused by the El Niño event persisted for a period after the event itself.

The population estimates for the Sumatran rhino of 20 to 33 rhino pre-El Niño and 7 to 16 rhino post-El Niño is a best estimate. The annual index of relative abundance showed a dramatic fall in the period immediately following the El Niño event with no significant recovery within the following three years (Fig. 11). Even with the absence of dead rhino being found and the limitations imposed by the data and methodology, the evidence for a significant reduction in rhino numbers resulting from the El Niño draught and forest fires is compelling. The upper range for a population reduction of 77-87 percent calculated from the index of relative abundance is probably too high. The maximum level of the index was in 1997 which may have been inflated by the act of dispersion of the rhino population during the drought and fires, and depressed afterwards as the population was already dispersed. The lower limit of 54 to 55 percent reduction however is consistent with the reduction in the estimated population size.

Some ecological information about the Sumatran rhino was gathered. The distribution of rhino is consistent with the preference for closed forest as expected. van Strien (1986) noted that Sumatran rhino appeared to avoid of open areas. Contrary to expectations there was no significant difference found between traps in open (n = 6) and closed areas (n = 21). The lack of significance is probably due to an imbalanced sample and confounded by other factors such as topographic compression (Griffiths 1993).

The activity of the rhinos was found to be significantly nocturnal (Fig. 12). Franklin (2003) showed that tigers and their prey were active during the day (their prey significantly so) making it unlikely that human disturbance is the cause of the nocturnal behaviour (Griffiths & Schaik 1993). The data also corresponds with observations of Sumatran rhino in the Gunung Leuser National Park (Griffiths 1993). The Sumatran rhino may have a preference to nocturnal activity to avoid biting insects often absent at night and spend much of the day wallowing as a protection against them.

The sex ratio of the adult rhinos is inconclusive (4 males, 3 females, 3 unknown) but not inconsistent with the apparent even ratio found by van Strien (1986). One calf (J1) was born during the study and was photographed twice in late 1997 once with his mother and once independently. The calf was estimated from size and form to be approximately eight to twelve months old by comparison with photographs of a calf born at Cincinnati Zoo (T.L. Roth pers. comm.). The cow (F1) photographed with calf at this time was still lactating from the appearance of the udder (N.J. van Strien pers. comm.; T. Roth pers. comm.). Although the calf was photographed by itself shortly after the first photograph it is considered most likely that the cow-calf pair had not separated at this point but F1 appeared absent due to the programmed time delay in the camera trap. One other photograph of an unidentified lactating cow was taken prior to this, the timing of which can not exclude it as being F1 shortly before or just after J1's parturition. None of the photographs of rhino post-El Niño were identified as females, however the sign of female and calf were found by the RPU in 2000 (Hutabarat *et al.* 2001).

The Sumatran rhino population in the park of 20 to 33 animals was a significant portion of the world population prior to 1997. The present reduced population size of 7 to 16 Sumatran rhino raises serious concerns for its future survival. It appears that the current population has passed through at least one bottle neck prior to the 1997 El Niño event, and is likely to do so again with the predicted increase in frequency and magnitude of El Niño events. With each bottle neck the risk of extinction of the population due to stochastic and genetic factors increases which can be magnified further by poaching. One young male rhino died in the park in 2000, possibly as a result of wounds inflicted by illegal armed 'sport' hunters highlighting the need for protection. There is sufficient habitat within the park to enable a population of at least 60 rhino but even with protection from poaching it may never reach this target as a result of episodic climatic induced catastrophes.

Acknowledgements

The author is grateful to the Directorate General of Forestry Protection and Nature Conservation, Ministry of Forestry Indonesia, for granting permission for this study to be undertaken and to Pak Waldemar of the Sumatran Tiger Program and Pak Hutabarat of the Indonesian Rhino Conservation Program for making the data available. The author is also grateful to Ron Tilson, Tom Foose, Nico van Strien, and Neil Franklin for their help and support, and to Jeremy Searle for his advice during the preparation of this manuscript. The author wishes to especially thank the Indonesian staff of the respective programmes, too numerous to mention, but whose work makes such studies possible and without which there would be no future for the Sumatran rhino and tiger.

Word Count 6,200

References

Borner, M. (1979) *A Field Study of The Sumatran Rhinoceros* Dicerorhinus sumatrensis *Fisher 1814. Ecology and behaviour conservation situation in Sumatra.* PhD thesis, University of Basel, Basel.

Carbone, C., Christie, S., Conforti K., Coulson, T., Franklin N., Ginsberg, J.R., Griffiths, M., Holden, J., Kawanishi, K., Kinnaird, M., Laidlaw, R., Lynam, A., Macdonald, D.W., Martyr D., McDougal, C., Nath, L., O'Brian, T., Seidensticker, J., Smith, D.J.L., Sunquist M., Tilson, R. & Wan Shahruddin, W.N. (2001) The use of photographic rates to estimate densities of tigers and other cryptic mammals. *Animal Conservation*, **4**, 75-79.

Dinerstein, E. (1991) Demography and habitat use by Greater One-Horned rhinoceros in Nepal. *Journal of Wildlife Management*, **55**, 401-411.

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

Foose, T.J. & van Strien, N.J. (1997) *Asian Rhinos – Status Survey and Conservation Action Plan.* IUCN, Gland.

Foose, T.J. & van Strien, N.J. (1998) Conservation programmes for Sumatran and Javan rhinos in Indonesia and Malaysia. *Pachyderm*, **26**, 100-115.

Franklin, N. (2003) *Conservation Biology of the Sumatran Tiger in Way Kambas National Park, Sumatra, Indonesia.* Ph. D. thesis, University of York, York.

Franklin, N., Bastoni, Sriyanto, Siswomartono, D., Manansang, J. & Tilson, R. (1999) Last of the Indonesian tigers: a cause for optimism. *Riding the Tiger: Tiger conservation in human-dominated landscapes* (eds. J. Seidensticker, S. Christie & P. Jackson), pp. 130-147. Cambridge University Press, Cambridge.

Griffiths, M. (1993) *The Javan Rhino of Ujung Kulon: An investigation of its population and ecology through camera trapping.* A report to The Directorate General of Forest Protection and Nature Conservation and World wide Fund for Nature, Indonesia Programme, Jakarta.

Griffiths, M. (1994) Population density of Sumatran tigers in Gunung Leuser National Park. *Sumatran Tiger Population and Habitat Viability Analysis Report* (eds R. Tilson K. Soemarna, , W. Ramono, S. Lusli, K. Traylor-Holzer & U. Seal). IUCN/SSC Conservation Breeding Specialist Group Species Survival Commission of the, Minnesota.

Griffiths, M. & van Schaik, C.P. (1993) The impact of human traffic on the abundance and activity periods of Sumatran rain forest wildlife. *Conservation Biology*, **7**, 623-626.

Hutabarat, A.A., Subrata, D.D. & van Strien N.J. (2001) *Indonesian Rhino Conservation Programme (IRCP) 2000 annual report and summary of relevant data.* IRCP, Bogor.

IUCN (2002). *2002 IUCN Red List of Threatened Species.* http://www.redlist.org. Downloaded 20 April 2003.

Karanth, K.U. (1995) Estimating tiger *Panthera tigris* populations from camera-trap data using capture-recapture models. *Biological Conservation*, **71**, 333-338.

Karanth, K.U. & Nichols J.D. (1998) Estimation of tiger densities in India using photographic captures and recaptures. *Ecology*, **79**, 2852-2862.

Kinnaird, M.F. & O'Brian, G. (1998) Ecological effects of wildfire on lowland rainforest in Sumatra. *Conservation Biology*, **12**, 954-956.

Kinnaird, M.F., Sanderson, E.W., O'Brian T.G., Wibisono, H.T. & Woolmer, G. (2003) Deforestation trends in a tropical landscape and implications for endangered large mammals. *Conservation Biology*, **17**, 245-257.

Lizcano, D.J. & Cavelier J. (2000) Daily and seasonal activity of the mountain tapir (*Tapirus pinchaque*) in the Central Andes of Colombia. *Journal of Zoology*, **252**, 429-435.

Poleti, G., Mui, T.V., Dang, N. X., Manh, B.H. & Baltzer, M. (1999) The Javan rhinos, *Rhinoceros sondaicus annamiticus*, of Cat Tien National Park, Vietnam: current status and management implications. *Pachyderm*, **27**, 34-48.

Reilly, J., Hills Spedding, G. & Apriawan (1997) Preliminary observations on the Sumatran rhino in Way Kambas National Park, Indonesia. *Oryx*, **31**, 143-150.

van Schaik, C.P. & Griffiths, M. (1996) Activity periods of Indonesian rain forest mammals. *Biotropica*, **28**, 105-112.

Shadwick, R.E., Russell, A.P. & Lauff, R.F. (1992) The structure and mechanical design of rhinoceros dermal armor. *Philosphical Transactions of the Royal Society of London Series B*, **337**, 419-428.

Siswomartono, D., Reddy, S., Ramono, W., Manansang, J., Tilson, R., Franklin, N. & Foose, T.J. (1996) The Sumatran rhino in Way Kambas National Park, Sumatra, Indonesia. *Pachyderm*, **21**, 13-14.

Stolle, F. & Tomich T.P. (1999) The 1997-1998 fire event. *Nature & Resources*, **35**, 22-30.

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

Wells, P.L. (2000) *Rhino Protection Units, Way Kambas National Park: Summary and Assessment of Activities 1998*. Report for the US Fish & Wildlife Service, International Rhino Foundation & WWF International, Bogor.

Wells, P.L., Franklin, N. & Rubianto A. (1994) Preliminary report on the current status of the Sumatran rhino in Bengkulu region of Kerinci Seblat National Park. *Sumatran Rhino Population and Habitat Viability Analysis, Bandar Lampung, South Sumatra, 1993* (eds K. Soemarna, R. Tilson, W. Ramono, D.W. Sinaga, R. Sukumar, T.J. Foose, K. Traylor-Holzer & U. Seal). IUCN/SSC Conservation Breeding Specialist Group Species Survival Commission of the, Minnesota.

White, G.C., Anderson, D.R., Burnham, K.P. & Otis, D.L. (1982) *Capture-recapture and removal methods for sampling closed populations*. Los Alamos National Laboratory Publication LA-8787-NERP, Los Alamos.

Wind, J., Djoko, S. & Waladi, I. (1979) *Way Kambas Management Plan 1980-1985*. FAO/INS/78/061, Report 5, Bogor.

Worton, B.J. (1989) Kernel methods for estimating the utilization distribution in home-range studies. *Ecology*, **70**, 164-168.