Gajah 29 (2008) 17-23

Elephant Crop Raiding in a Disturbed Environment: The Effect of Landscape Clearing on Elephant Distribution and Crop Raiding Patterns in the North of Aceh, Indonesia

Ente J. J. Rood[1,2,3], Wahdi Azmi[2] and Matt Linkie[2,4]

[1]*Zoological Museum Amsterdam, University of Amsterdam, The Netherlands*
[2]*FFI-Aceh, Aceh Forest and Environment Project, Banda Aceh, Indonesia*
[3]*Department of Anthropology & Geography, Oxford Brookes University, Oxford, UK*
[4]*Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, UK*

Introduction

The Sumatran elephant (*Elephas maximus sumatranus)* still occurs over 44 subpopulations scattered across much of their historical range all over the island of Sumatra (Heurn 1929; Hedges *et al.* 2005). However, the persistence of many populations is threatened by habitat loss, poaching, and direct conflict with humans (Santiapillai & Jackson 1990; Leimgruber *et al*. 2003; Nyhus & Tilson 2004; Hedges *et al*. 2005). The Sumatran elephant is listed as Endangered in the 2004 IUCN Red List of Threatened Species (IUCN 2008), and is included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; UNEP-WCMC 2003).

Over the last decade, elephant conservation across the island of Sumatra has increasingly been coping with the occurrence of conflict between humans and wild ranging elephants (Nyhus *et al.* 2000; Rood 2006; Linkie *et al*. 2007). Continuous forest conversion for the purpose of plantation development, wood extraction and the opening of community gardens has virtually eliminated all lowland habitats (Leimgruber *et al*. 2003). Elephants have been forced to move to the forested slopes of mountain ranges where they frequently enter gardens and raid crops (Nyhus *et al.* 2000; Nyhus & Tilson 2004; Linkie *et al*. 2007). The current landscape configuration, in which small patches of degraded forests are interspersed with small-scale gardens and plantations, are believed to facilitate the occurrence of human-elephant conflict (Hoare 1999; Sitati *et al*. 2005; Rood 2006). As elephant habitat gets increasingly encroached by human settlers, the reduction of available habitat within the historically occupied elephant range has led to an increase of elephants raiding crops (Linkie *et al*. 2004; Sitati et al. 2005). In some cases, the total conversion of elephant habitat has left elephants residing in a landscape dominated by humans. This has eventually led to frequent encounters between humans and elephants with both human as well as elephant lethal casualties as a result (pers. obs.).

A number of studies have tried to focus on the processes underlying the occurrence of crop raiding (Sukumar 1990; Barnes 1996; Hoare 1999; Hoare 2000; Williams *et al.* 2001; Osborn & Parker 2003; Sitati *et al*. 2003; Zhang & Wang 2003; Fernando *et al*. 2005; Sitati *et al*. 2005; Venkataraman *et al*. 2005; Webber *et al*. 2007). Many of these studies have mentioned habitat destruction as an ultimate cause of the occurrence of crop raiding (CR). However, even though widely accepted (Hoare 1999; Sitati *et al*. 2003; Williams *et al*. 2001; Sitati *et al.* 2005), no work has been undertaken to quantify to which extent deforestation or forest configuration shapes the spatial pattern of CR. This paper describes the patterns of HEC occurring over the province of Aceh, North Sumatra, by means of forest configuration and topological descriptors. Elephant distribution data and CR patterns will be compared by means of landscape descriptors, forest cover data and forest clearing patterns. Consequently, elephant distribution patterns will be compared to the occurrence of human-elephant conflict to assess to which extent elephants are being displaced from their natural habitat.

The patterns of CR on a landscape scale will be compared with forest configuration and forest clearing patterns. The occurrence of CR is generally believed to emerge from habitat degradation and consequently, a decrease in resource availability. As the existing suitable habitat within elephants' home ranges gets increasingly fragmented by human encroachment, the encounters between humans and elephants are expected to increase. Therefore, an increase in CR is expected with increasing habitat fragmentation. Secondly, forest clearance over the past three decades, has often completely depleted all forest from the historic ranges of several elephant groups in Aceh. If elephants are constrained to their historic ranges being unable to move into forested areas, CR is expected to occur as a result of displacement and will therefore be frequent in areas that have been subjected to forest clearing in the past. However, if elephants are able to endure continuous habitat alteration by moving into alternative forested habitats, the occurrence of human-elephant conflict will not solely occur in recently cleared areas but is more likely to decrease with the total amount of forest cover available to elephants within their historic home range.

The effect of landscape topology will be used to assess the effect of landscape characteristics on elephants. Elephants are wide ranging animals that have been found to move over distances up to 52 km (Sukumar 1989). Elephant movements through the landscape will therefore be constrained by a number of parameters describing landscape characteristics such as elevation, slope, and elevation heterogeneity. Therefore, we hypothesize that the occurrence of human-elephant conflict will depend on landscape characteristics describing accessibility to elephants.

Methods

Study area

Data was collected within the forests of northern Aceh, ranging from 95°25'E-96°40'E and 05°30'N-04°08'N (Fig. 1). The geology of the area is dominantly sandstone or granite, but limestone formations are common along the west coast. The study area completely covers the nature reserve of Cagar Alam Jantho and the majority of the Leuser ecosystem, which still support large tracts of intact lowland and montane rainforest. The vegetation is dominated by dipterocarp rainforest interspersed with patches of pine forests, disturbed or secondary forests and *Imperata cylindrica* dominated grasslands. Most of the area has a protected status, but traces of prior logging concessions, which had been abandoned due to the armed conflict, can be found up to 20 km into the forest. Current logging activities are illegal but nevertheless rampant throughout the area. Moreover, between 1980 and 2000, 20% of the total forest cover got cleared, mainly for wood trade.

Elephant distribution dataset

During two field seasons ranging from April to August in the consecutive years of 2006 and 2007, data on elephant distribution was recorded across the north of Aceh. Data collection was conducted following a systematic stratified sampling design. This was achieved by stratifying the landscape according to 500 m elevation intervals and three landcover classes (forest, non-forest, plantation). Within each stratum, five random sites of 1 x 1

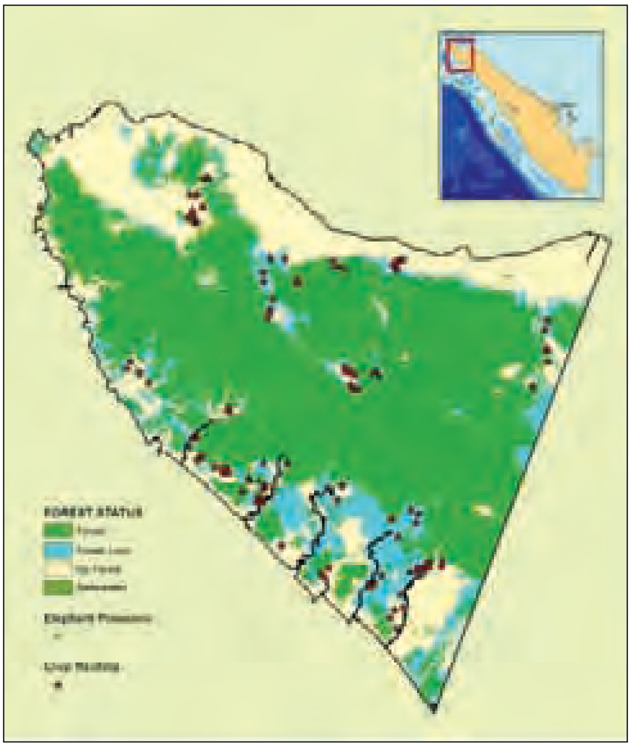

Figure 1. Deforestation across the north of Aceh.

km were selected and plotted on a map. Within each site one 250 x 200 m plot was set out and sampled by means of five 200 x 5 m wide strip transects. While walking transects, each elephant track (and other species tracks) encountered were recorded, along with the time, habitat type, elevation, slope and GPS position.

Crop raiding dataset

Between 1985 and 1997, 62 records of human-elephant conflict (HEC) were collected over the whole of Aceh, all of which originated from interview reports with local communities. From the years 2000 to 2006 another 316 incident records and interviews were conducted using different descriptors to assess causes of HEC. None of these reports, however, provide any constant estimation of HEC intensity. As most of the reports used for analysis were collected opportunistically, or when HEC escalated (reports from the Indonesian conservation agency, e.g. BKSDA). The available data, however, does provide a good representation on the occurrence patterns of HEC over time. For the purposes of this study, only the crop raiding records compiled between 2000 and 2007, resulting in a total dataset of 120 CR events, were used in the analysis.

Landscape descriptors

Distribution patterns of elephants and CR data were analyzed by means of five landscape descriptors produced using ArcGIS 9.3 (ESRI). Two topographical descriptors were used to assess the relative importance of elevation heterogeneity on the occurrence of elephants including: 1) elevation heterogeneity based on a 90 x 90 m digital elevation model (http://glcfapp.umiacs.umd.edu:8080/esdi/index.jpg). 2) landscape curvature was calculated. However, since this descriptor appeared to be highly correlated to the elevation heterogeneity index it was discarded from the analysis. Forest configuration descriptors included: 1) proportion of forest cover within a 2 km radius of the focal cell, 2) the proportion of forest logged between 1880-2000, within a 2 km distance of the focal cell, and 3) the number of forest patches larger than 1 ha within a 5 km radius of the focal cell, 4) distance to previously logged area. To enable comparisons between individual landscape descriptors, all landscape maps were standardized before analysis.

Data analysis

For this study, ecological niche factor analysis (ENFA) was used to calculate the relative contributions of a set of landscape descriptors to predict elephant distribution and CR-patterns (Hirzel & Arlettaz 2003). ENFA compares the distribution of presence observations in a multidimensional space of environmental variables to the environmental variance across the entire study area (Hirzel *et al*. 2002; Hirzel & Arlettaz 2003; Hirzel *et al.* 2006). The relative contribution of a certain predictor is calculated based on factors (similar to a PCA) that define: 1) how the species mean habitat characteristics differ from the mean available habitat present in the entire area (marginality), and 2) the overall variance of habitat characteristics to the species habitat variance (specialization). To enable comparisons between the elephant distribution data and the CR distribution data, the same set of landscape descriptors were used in the analysis of both data sets.

Subsequently, a discriminant analysis was preformed to investigate how each of the descriptors discriminates between the two datasets (Legendre 1998). Like the ENFA, this multivariate analysis works in the space defined by the descriptors but it uses the distributions of both datasets to calculate an index that maximizes the interspecific variance while minimizing the intraspecific variance. Therefore, the discriminant factor is the direction along which the two species differ the most, i.e. it is correlated with the variables on which they are most differently distributed. To analyze the amount of overlap in the occurrence of CR and elephant occurrence, both datasets were plotted against their relative discriminant scores and a one-tailed T-test was applied to test for significant differences between population means.

Statistical analysis were preformed using Biomapper 4.0 and Openstat statistical software which are freely available online.

Table 1. Results of the discriminant analysis.

Descriptor	ED* Marg. (71%)	89% Spec1 (18%)	CR* Marg. (83%)	94% Spec1 (11%)	DA 80% DA-Factor
Elev. heterog.	-0.062	0.473	-0.343	0.147	0.545
Dist. logged area	-0.783	0.437	-0.425	-0.883	0.509
Forest cover	0.359	0.566	-0.503	0.402	0.520
Fragmentation	0.461	0.148	0.251	-0.121	-0.367
Prop. logged	0.204	0.493	0.621	-0.149	-0.197

*ED = elephant distribution, CR = crop raiding

Results

Elephant distribution

The first factor of the ENFA analysis, which describes the distance between the average landscape conditions in which elephants were found present and the average conditions present in the entire study area, appeared to account for 89% of the variance present in the elephant distribution dataset (Table 1). The correlations between the first (marginality) factor and the landscape descriptors shows that elephant occurrences were most often found in, or close to areas which have been logged between 1980-2000 (marginality score = -0.783). Furthermore, elephants appeared to inhabit areas that still had intermediate levels of forest cover (marginality score = 0.359) and were moderately fragmented (marginality score = 0.461). The marginality score explained 71% of the total variation present in the dataset implicating that most of the species specialization is been accounted for by the species marginality (e.g. their deviation from the average conditions in the study area).

Crop raiding patterns

ENFA analysis of the CR pattern showed that the 5 landscape predictors used in this analysis accounted for 94% of the variation between CR events present in the dataset (Table 1). The marginality score (distance from the average conditions) shows that the occurrence of crop raiding occurs most frequently in or near areas, which have previously been logged (marginality score = -0.883). However CR appeared to be moderately correlated to current forest cover (marginality score = 0.402) indicating that CR is most likely to occur in areas, which are still partially forested. Nevertheless 74% of the CR events occurred within logged areas and 25% of the CR events took place in areas, which had no forest cover within a 2 km radius of the CR location.

Discriminant analysis

The results of the discriminant analysis are given in Table 1. Even though the discriminant analysis does not completely differentiate between the occurrence of CR and the presence of elephants (a reasonable amount of overlap exists between the two datasets, Fig. 2), the group means are significantly different (one tailed T-test: t=9.9, p<0.0001, Fig. 3). This indicates that the occurrence of CR and the occurrence of wild ranging elephants can be significantly separated based on the five landscape descriptors used for this analysis.

The distribution of elephant presences and CR events along the DA factor (Fig. 2, Table 1) reveals that a high proportion of forest cover and an increase in elevation heterogeneity correlate

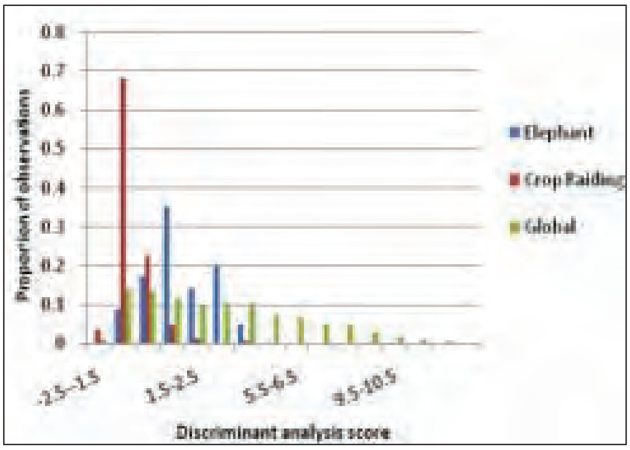

Figure 2. Distribution of elephant distribution records, CR events and the global distribution of all cells along the discriminant factor.

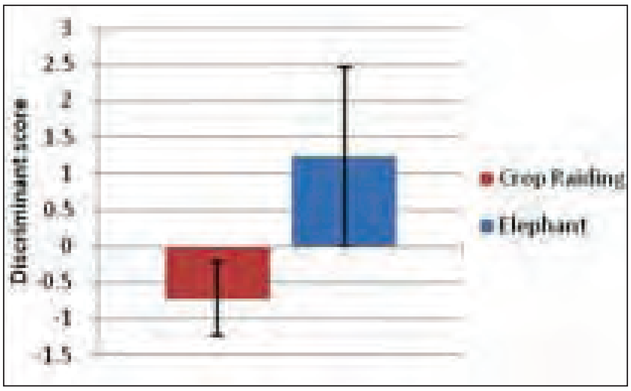

Figure 3. Average discriminant score for elephant presences and CR events. Error bars indicate standard deviations from the population mean. Population means are significantly different.

with elephant presence (Table 1, Fig. 2). On the other hand an increase in landscape fragmentation correlates with the occurrence of CR events. The single factor on which both groups cannot be separated is the proportion of forest logged between 1980-2000. This indicates that the observed overlap is concentrated within areas that had been logged over the last 30 years.

Conclusions

The results of the analysis presented in this study show that intermediate habitat fragmentation does not displace elephants from their natural ranges. The spatial matrix of secondary forest and agricultural areas near primary forest provide sufficient habitat for the elephants to prevail. As forested areas are partially opened for agricultural purposes, elephants will reside and utilize the subsequent regrowth as a resource of protein rich foliage. Furthermore, the remaining forested patches are still used and are likely to provide shelter for the elephants during the day.

However, as conversion of lowland habitat continues, elephants do not respond by moving to alternative areas, but are forced to reside in smaller patches of less suitable habitat. Therefore, the currently observed distribution of elephants across the landscape might not only be determined by the availability of resources, but is to a large extent shaped by historic ranges and movements. This will inevitably lead to the situation in which natural elephant habitat is totally converted and the remaining groups permanently reside in a matrix of secondary forest and agricultural landscape. In order to adapt to this new situation, elephants start exploiting the newly established resources (agriculture and secondary regrowth) to meet their dietary demands, with an increase in crop raiding as a result.

The results of the ENFA analysis demonstrate that the occurrence of crop raiding by elephants appears to be concentrated in logged areas on the forest border. This finding supports the scenario in which elephants are being displaced and persevere within the remaining forested areas. Surprisingly an increase in forest fragmentation does not explicitly lead to an increase of crop raiding. Seemingly, elephants, which inhabit highly fragmented, but still moderately forested areas, do not necessarily raid crops. Yet, as the remaining forest patches are being cleared for agricultural expansion, the incidence of crop raiding by elephants increases. Even if all forest within an elephant's range is completely cleared, they are likely to continue to dwell within their historic range and will not move into new areas.

Discriminant analysis of our data showed that the elephant distribution patterns and CR patterns clearly distinguish between forested habitats and opened forest. Also, elephants inhabit hilly terrain that is less suitable for agriculture, this leads to a low incidence of CR in moderately hilly terrain. The high overlap between the occurrence of elephants and CR in logged areas supports the fact that elephants more frequently occupy forested areas, and supports the idea that elephant populations are being displaced from their natural habitat. Consequently as forest borders are shifted to an extent that elephants are forced to move into highly rugged mountain terrain, elephants are forced to rely on agricultural areas to forage. In such cases, the scale and extent of crop raiding and encounters between humans and elephants are prone to increase to a critical extent.

Implications for conservation

The implication that elephant habitat use is limited by the total area of forested area within lowland areas of moderate elevational variation (e.g. flat land to lowland hills) means that further clearance of these areas could lead to a total deterioration of available habitat and will ultimately lead to a rise in human elephant conflict and further population declines. As land use planning for conservation landscapes within and outside accomplished conservation areas is becoming a new standard in large mammal conservation practices, the effects of land use configuration, elephant behavior and human response are the most important issues to account for when dealing with elephant conservation (O'Connell-Rodwell *et al*. 2000; Leimgruber *et al.* 2003; Venkataraman *et al*. 2005).

Continuous forest clearance and habitat degradation will ultimately lead to an increased encounter rate between human residents and wild elephants, and consequently to intensification of human elephant conflict (Linkie *et al.* 2004; Linkie *et al.* 2007). Since the larger area of natural elephant ranges lie outside protected areas, appropriate conservation management and efficient land use will be of critical importance and essential to minimize conflict and to guarantee the prevalence of local elephant populations. Land use zoning and forest rehabilitation should therefore be used to segregate areas of human interest and elephant habitat. Buffer zones should maximize the distance between suitable elephant habitat and human populated areas by minimizing resource extraction by humans, and simultaneously offer carrying capacity for elephants displaced by rural development.

Acknowledgements

This work was conducted as a part of the FFI-Aceh Aceh Forest and Environment Program, funded by Multi Donor Fund. We would like to thank Indonesian Ministry of Forestry Directorate General of Forest Protection and Nature Conservation (PHKA) for providing permission to work in the area and the Indonesian Conservation institute (BKSDA) for sharing data. Our special gratitude goes out to our colleagues in the protected areas division of FFI-AFEP, who have greatly contributed to realize this manuscript. We would like to thank Iep and Torro for their support with collecting human elephant conflict data and the field staff for their tremendous effort to collect elephant distribution data under harsh field conditions.

References

Barnes, R.F.W. (1996) The conflict between humans and elephants in the central African forests. *Mammal Review* **26:** 67-80.

Fernando, P., Wikramanayake, E., Weerakoon, D., Jayasinghe, L.K.A., Gunawardene, M. & Janaka, H.K. (2005) Perceptions and patterns of human-elephant conflict in old and new settlements in Sri Lanka: Insights for mitigation and management. *Biodiversity and Conservation* **14:** 2465-2481.

Hedges, S., Tyson, M.J., Sitompul, A.F., Kinnaird, M.F., Gunaryadi, D. & Aslan (2005) Distribution, status, and conservation needs of Asian elephants (*Elephas maximus*) in Lampung Province, Sumatra, Indonesia. *Biological Conservation* **124:** 35-48.

Heurn, F.C. (1929) *De olifanten van Sumatra*. Den Haag.

Hirzel, A.H. & Arlettaz, R. (2003) Modeling habitat suitability for complex species distributions by environmental-distance geometric mean. *Environmental Management* **32:** 614-623.

Hirzel, A.H., Hausser, J., Chessel, D. & Perrin, N. (2002) Ecological-niche factor analysis: How to compute habitat-suitability maps without absence data? *Ecology* **83:** 2027-2036.

Hirzel, A.H., Le Lay, G., Helfer, V., Randin, C. & Guisan, A. (2006) Evaluating the ability of habitat suitability models to predict species presences. *Ecological Modelling* **199:** 142-152.

Hoare, R. (2000) African elephants and humans in conflict: the outlook for co-existence. *Oryx* **34:** 34-38.

Hoare, R.E. (1999) Determinants of human-elephant conflict in a land-use mosaic. *Journal of Applied Ecology* **36:** 689-700.

Legendre, L. & Legendre P. (1998) *Numerical Ecology*. Elsevier: Amsterdam.

Leimgruber, P., Gagnon, J.B., Wemmer, C., Kelly, D.S., Songer, M.A. & Selig, E.R. (2003) Fragmentation of Asia's remaining wildlands: implications for Asian elephant conservation. *Animal Conservation* **6:** 347-359.

Linkie, M., Dinata, Y., Nofrianto, A. & Leader-Williams, N. (2007) Patterns and perceptions of wildlife crop raiding in and around Kerinci Seblat National Park, Sumatra. *Animal Conservation* **10:** 127-135.

Linkie, M., Smith, R.J. & Leader-Williams, N. (2004) Mapping and predicting deforestation patterns in the lowlands of Sumatra. *Biodiversity and Conservation* **13:** 1809-1818.

Nyhus, P., & Tilson, R. (2004) Agroforestry, elephants, and tigers: balancing conservation theory and practice in human-dominated landscapes of Southeast Asia. *Agriculture Ecosystems & Environment* **104:** 87-97.

Nyhus, P.J., Tilson, R. & Sumianto (2000) Crop-raiding elephants and conservation implications at Way Kambas National Park, Sumatra, Indonesia. *Oryx* **34:** 262-274.

O'Connell-Rodwell, C.E., Rodwell, T., Rice, M. & Hart, L.A. (2000) Living with the modern conservation paradigm: can agricultural communities co-exist with elephants? A five-year case study in East Caprivi, Namibia. *Biological Conservation* **93:** 381-391.

Osborn, F.V. & Parker, G.E. (2003) Towards an integrated approach for reducing the conflict between elephants and people: a review of current research. *Oryx* **37:** 80-84.

Rood, E.J.J. (2006) *The Status and Distribution of the Sumatran Elephant in Aceh, Indonesia*. WWF, Yayasan Gajah Sumatra, Amsterdam.

Santiapillai, C. & Jackson, P. (1990) *The Asian Elephant: An Action Plan for Its Conservation*. IUCN/SSC Asian Elephant Specialist Group Gland, Switzerland.

Sitati, N.W., Walpole, M.J. & Leader-Williams N. (2005) Factors affecting susceptibility of farms to crop raiding by African elephants: using a predictive model to mitigate conflict. *Journal of Applied Ecology* **42:** 1175-1182.

Sitati, N.W., Walpole, M.J., Smith, R.J. & Leader-Williams, N. (2003) Predicting spatial aspects of human-elephant conflict. *Journal of Applied Ecology* **40:** 667-677.

Sukumar, R. (1989) Ecology of the Asian elephant in southern India. 1. Movement and habitat utilization patterns. *Journal of Tropical Ecology* **5:** 1-18.

Sukumar, R. (1990) Ecology of the Asian elephant in southern India. 2. Feeding-habits and crop raiding patterns. *J. of Trop. Ecology* **6:** 33-53.

Venkataraman, A.B., Saandeep, R., Baskaran, N., Roy, M., Madhivanan, A. & Sukumar, R. (2005) Using satellite telemetry to mitigate elephant-human conflict: An experiment in northern West Bengal, India. *Current Science* **88:** 1827-1831.

Webber, A.D., Hill, C.M. & Reynolds, V. (2007) Assessing the failure of a community-based human-wildlife conflict mitigation project in Budongo Forest Reserve, Uganda. *Oryx* **41:** 177-184.

Williams, A.C., Johnsingh, A.J.T. & Krausman, P.R. (2001) Elephant-human conflicts in Rajaji National Park, northwestern India. *Wildlife Society Bulletin* **29:** 1097-1104.

Zhang, L., & Wang, N. (2003) An initial study on habitat conservation of Asian elephant (*Elephas maximus*), with a focus on human elephant conflict in Simao, China. *Biological Conservation* **112:** 453-459.

Corresponding author's e-mail:
erood@science.uva.nl