Available online at www.sciencedirect.com
SCIENCE DIRECT®
Biological Conservation 124 (2005) 35–48
BIOLOGICAL CONSERVATION
www.elsevier.com/locate/biocon

Distribution, status, and conservation needs of Asian elephants (*Elephas maximus*) in Lampung Province, Sumatra, Indonesia

Simon Hedges [a,*], Martin J. Tyson [a,b], Arnold F. Sitompul [a,c], Margaret F. Kinnaird [a,d], Donny Gunaryadi [a], Aslan [a]

[a] *Wildlife Conservation Society – Indonesia Program, P.O. Box 311, Bogor 16003, Indonesia*
[b] *Conservation Biology Unit, Department of Biological Sciences, The Manchester Metropolitan University, Manchester M1 5GD, UK*
[c] *Warnell School of Forest Resources, The University of Georgia, Athens 30602, USA*
[d] *National Center for Ecological Analysis and Synthesis, 735 State Street, Suite 300, Santa Barbara, CA 93101, USA*

Received 15 April 2004

Abstract

In the mid 1980s, Asian elephant (*Elephas maximus*) populations were believed to persist in 44 populations on the Indonesian island of Sumatra. Twelve of these populations occurred in Lampung Province, but our surveys revealed that only three were extant in 2002. Causal factors underlying this decline include human population growth, changes in land use, and human–elephant conflict. Nevertheless, our surveys in the Province's two national parks, Bukit Barisan Selatan and Way Kambas, produced population estimates of 498 (95% CI = [373, 666]) and 180 (95% CI = [144, 225]) elephants, respectively. The estimate for Bukit Barisan Selatan is much larger than previous estimates; the estimate for Way Kambas falls between previous estimates. The third population was much smaller and may not be viable. These are the first estimates for Southeast Asian elephant populations based on rigorous sampling-based methods that satisfied the assumptions of the models used, and they suggest that elephant numbers in these parks are of international importance. While our results suggest that Sumatra's remaining elephant populations may be larger than expected, they also suggest that the future for these animals is bleak. Human–elephant conflict was reported around all three areas in Lampung and their elephant populations are currently threatened by habitat loss and poaching. Local solutions are possible, but will require much greater commitment by all stakeholders.

Keywords: Asian elephant; *Elephas maximus*; Indonesia; Survey; Conservation

1. Introduction

Asian elephants (*Elephas maximus*) still occur in isolated populations across much of their historical range, but many populations are threatened by habitat loss, poaching, and direct conflict with humans (Santiapillai and Jackson, 1990; Sukumar, 1992; Duckworth and Hedges, 1998; Blake and Hedges, 2004). The species is listed as Endangered in the *2004 IUCN Red List of Threatened Species* (IUCN, 2004), and is included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; UNEP-WCMC, 2003). Nevertheless, little is known about the status of Asian elephant populations.

* Corresponding author. Present address: Wildlife Conservation Society – International Programs, c/o 1 Kearstwick Cottages, Kearstwick, Kirkby Lonsdale, Cumbria LA6 2EB, UK. Tel.: +44 1524 273408.
E-mail addresses: simon.hedges@zen.co.uk, shedges@wcs.org (S. Hedges).

0006-3207/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2005.01.004

For example, Duckworth and Hedges (1998) concluded that there were insufficient data to estimate national elephant population sizes in Indochina, and Sukumar (1992) provides only general estimates for the Indian subcontinent. It is no surprise, therefore, that the frequently cited global estimate of 34,500–51,000 Asian elephants is acknowledged as little more than an educated guess (Kemf and Santiapillai, 2000; WWF, 2002; Blake and Hedges, 2004).

While subspecies taxonomy of *E. maximus* has varied among authors, recent genetic work suggests that the Sumatran subspecies is monophyletic (Fleischer et al., 2001), and consequently this taxon could be defined as an evolutionarily significant unit (ESU). This further suggests that Sumatran elephants should be managed separately from other Asian elephants in captivity, and is also an argument for according particularly high priority to the conservation of Sumatran elephants in the wild.

Despite the importance of Sumatra's elephant populations, there has never been a systematic evaluation of the conservation status of elephant populations on the island, apart from the reconnaissance surveys of Blouch and Haryanto (1984) and Blouch and Simbolon (1985). These brief surveys indicated that elephants persisted in 44 discrete populations on Sumatra, with a total population size of 2800–4800 elephants; however, this estimate was in reality little more than an educated guess. Twelve of these populations were in Lampung Province, and it was thought that there were 550–900 elephants in Lampung, including those in Bukit Barisan Selatan National Park and Way Kambas National Park (Blouch and Haryanto, 1984; Santiapillai and Jackson, 1990).

Prior to the 1980s, information about Lampung's elephants was scarce. Nevertheless, it is clear that the province supported large elephant populations (Sody, 1925, 1939; Groeneveldt, 1938). The human population of Lampung began expanding particularly rapidly during the 1930s, initially under the Dutch colonial government's *Kolonisatie* Program, then, after independence, under the Indonesian government's transmigration programs. Furthermore, while many people moved to Lampung under the official transmigration program, many more people arrived independently (Benoit et al., 1989; Fearnside, 1997; Adhiati and Bobsien, 2001). As a result the human population increased more than 10-fold from 376,000 in 1930 to 5,250,000 in 1986 and the 33,307 km^2 province was radically transformed (Benoit et al., 1989). Currently, Lampung has the highest human population density of any Sumatran province (188 people/km^2; data from Indonesia's Central Bureau of Statistics, 2001).

These large numbers of people were not distributed evenly throughout Lampung. Early transmigrants were concentrated in the south but between 1980 and 1995 the government of Lampung resettled 70,000 families in northern Lampung under the Local Transmigration (*Translok*) program (Levang, 1997). At the beginning of the 1980s, northern Lampung was still relatively inaccessible and it is likely that the majority of Lampung's remaining elephants were in the northern part of the province (Blouch and Haryanto, 1984). The *Translok* program therefore had the unfortunate effect of converting many areas of elephant habitat into agricultural land, and this led to a major increase in levels of human–elephant conflict.

As the human population in Lampung increased, forest cover declined. In the early 1960s forest cover was still about 44% but by 1985 it had fallen to under 20% (Santiapillai and Suprahman, 1986; World Bank, 2001). This period of largely uncontrolled logging, which had in some areas left swathes of secondary forest and/or scrubby *Imperata* grassland that still provided elephant habitat, was followed by a period of forest conversion. This resulted from the decision to change the legal status of many of the heavily degraded forest blocks from Permanent Production Forest to Conversion Forest, and meant that the land could be cleared of remaining trees and used for agriculture (Benoit et al., 1989; Bowen and Borger, 2001). Largely as a result of these changes, forest cover in Lampung declined from approximately 19.1% in 1985 to approximately 10.8% in 1997, the second highest rate of any Sumatran province (World Bank, 2001).

The last 20 years in Lampung have therefore been characterized by near continuous human–elephant conflict and the wholesale loss of elephant habitat (Benoit et al., 1989; Santiapillai and Jackson, 1990; Lair, 1997; Levang et al., 1999; Nyhus et al., 2000; Reilly, 2002a). Since the mid 1980s, the Indonesian government's response to these problems involved capturing large numbers of elephants and moving them to Elephant Training Centers (ETCs), the first of which was established in Lampung in 1986 (Santiapillai and Jackson, 1990; Lair, 1997). By June 1996, there were six ETCs and a total of about 570 elephants had been captured (Lair, 1997). Part of the original justification for catching elephants was that they would be used in reduced impact logging operations, and for patrols and elephant-based ecotourism in Sumatra's national parks (McNeely, 1978; Lair, 1997). To date there has been little such use of ETC elephants (Suprayogi et al., 2002; authors' personal observations).

Despite these changes in human demography, land use patterns, and levels of human–elephant conflict, no recent data existed for Lampung's elephant populations except for the population in Way Kambas National Park (Reilly, 2002a). The objectives of our study were, therefore, to provide up to date information on elephant populations in Lampung with the aim of improving the conservation and management of the species. Specifically, we located all remaining elephant populations in the province and assessed their size and status. We also

assessed the current level of human–elephant conflict in the province, and evaluated the current condition of areas containing elephants and the threats faced by elephant populations.

2. Methods

2.1. Study areas

Lampung Province, which lies at the southern end of Sumatra, covers an area of 33,307 km^2 (Fig. 1). Rainfall is high, with between 2000 and 4000 mm per year, although during El Niño Southern Oscillation (ENSO) events there can be severe droughts. A dry season, usually of two to four months duration, occurs between May and October. The province contains two national parks, Bukit Barisan Selatan National Park (BBSNP) and Way Kambas National Park (WKNP), plus a number of smaller Protection Forests and several Production Forests. Protection forests are areas where logging is banned in order to protect watersheds and other environmentally sensitive areas. Production forests can be of three types: limited production forests, permanent production forests, and conversion forests. The latter can be clear-felled and converted to other land uses including agriculture and human settlements.

Bukit Barisan Selatan National Park, located in the western part of Lampung Province and the southern part of Bengkulu Province, is the third largest protected area (3568 km^2) on Sumatra. Santiapillai and Jackson (1990) ranked the park among the top four priority areas for elephant conservation on the island. The park's long thin shape results in over 700 km of boundaries, which combined with the lack of a buffer zone, the presence of agricultural enclaves, and recurrent encroachment by loggers and cultivators provides many opportunities for human–elephant conflict.

Way Kambas National Park (1235 km^2), in eastern Lampung, was ranked as the second highest priority area for Sumatran elephant conservation by Santiapillai and Jackson (1990). Way Kambas experiences high levels of human–elephant conflict (Nyhus et al., 2000), and houses Sumatra's largest ETC.

In addition to their importance for Asian elephants, both BBSNP and WKNP contain significant populations of Sumatran rhinoceroses (*Dicerorhinus sumatrensis*) and tigers (*Panthera tigris*; Foose and van Strien, 1997; Franklin et al., 1999; O'Brien et al., 2003).

2.2. Elephant distribution and abundance

We conducted dung-count surveys to estimate elephant population size and distribution in BBSNP and WKNP between September 2000 and March 2002. Between February and June 2002, we visited all the other areas of Lampung reported as having elephant populations in the early 1980s (Blouch and Haryanto, 1984).

We used a questionnaire to determine whether the presence of elephants was likely in the non-park survey blocks. We asked villagers to list mammalian pests visiting their agricultural fields and avoided asking leading questions about elephants. Once the formal questionnaire was completed, we asked the respondents about elephants in their area, human–elephant conflict, and elephant capture operations. We selected respondents

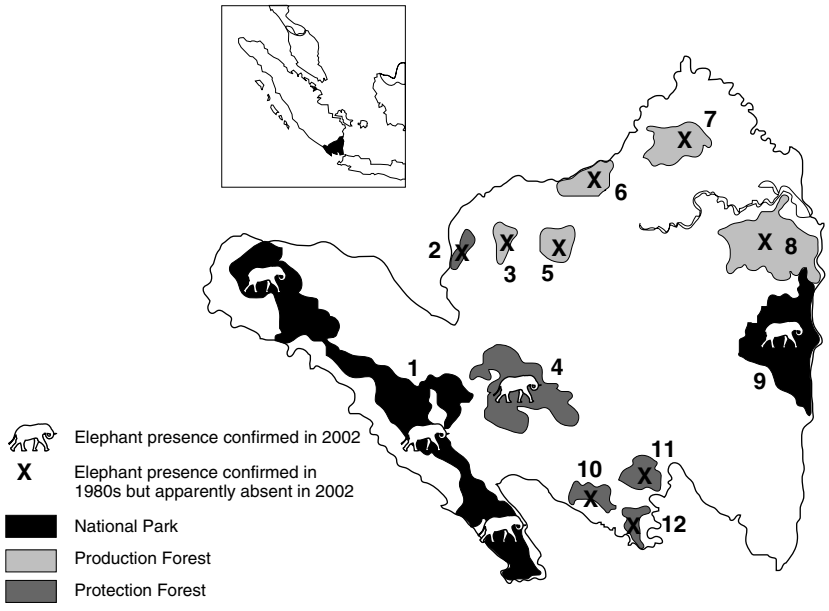

Fig. 1. Changes in Asian Elephant (*Elephas maximus*) distribution in Lampung Province, Sumatra, over the early 1980s to 2002 period. Numbers refer to site entries in Table 1.

knowledgeable about their areas, including people who hunted or gathered forest products in the survey blocks. All interviews were conducted in the Indonesian, Javanese, or Lampung languages.

Where there were reports of elephants, we used 'recce' transects (Walsh and White, 1999) to assess the location and abundance of elephant dung-piles. The 'recce' method involves walking along the path of least resistance through the forest and counting all dung-piles found. Walsh and White show that dung-pile encounter rates on 'recces' are strongly correlated with encounter rates on line transects. We used our initial 'recce' transect data to determine whether line transect surveys would also be needed in the non-park survey blocks.

We used standard line transect methods (Barnes and Jensen, 1987; Plumptre, 2000; Buckland et al., 2001), to determine the distribution and abundance of elephant dung-piles in BBSNP (1 May to 13 Nov 2001) and WKNP (26 Sept 2001 to 3 Mar 2002). Transects were surveyed once only; no permanent cut transects were used. We used a stratified random sampling design with two strata per park: 'high dung-pile density' and 'low dung-pile density'. For BBSNP, we defined these strata using the dung-pile encounter rates from our 'recce' surveys (low = 0–20 dung-piles/km; high = 20.1–45 dung-piles/km). For WKNP, we defined the strata using elephant distribution data from Santiapillai and Suprahman (1986) and Reilly (2002a), together with data gathered as we trained survey teams in April and May 2000. Separate estimates of dung-pile density were obtained for each stratum using the program DISTANCE (Thomas et al., 1998). Three models for the detection function were considered: half-normal, uniform, and hazard rate. In each case the need for adjustment terms was assessed using likelihood ratio tests. Choice of the final model was based on a combination of a low Akaike's information criterion (AIC) and a low variance (Buckland et al., 2001).

To convert estimates of dung-pile density to elephant density we collected defecation rate data for ten free-ranging elephants in WKNP over three periods, 6 June to 6 August 2000, 17 January to 2 April 2001, and 22 August to 26 October 2001 (Tyson et al., 2002). We also monitored dung-pile disappearance rates from July 2000 to December 2002 in BBSNP and from June 2000 to March 2002 in WKNP. Vegetation cover in both strata in BBSNP was generally forest. In WKNP, however, the low-density stratum was predominantly grassland and scrub, while the high-density stratum was predominantly secondary forest, and so we established strata-specific dung disappearance rates for WKNP. We used the DUNGSURV model of Hiby and Lovell (1991) to calculate duration periods for elephant dung-piles in the two parks. This approach relies on deriving a correction factor relating observed dung-pile density to elephant density, based on the probability of dung-piles dropped prior to the survey still being visible during the survey. The resulting estimates of elephant density were converted into elephant numbers using estimates of suitable elephant habitat (forest, scrub, grassland) in the two parks. These areas were calculated from satellite imagery (Section 2.3). Ninety-five percent log-normal confidence intervals were computed as described in Buckland et al. (2001).

2.3. Habitat condition

We measured changes in forest cover and land use in Lampung using LANDSAT Thematic Mapper satellite images for 1983–86 and 2000. All forest types (primary, secondary, degraded/logged) were lumped into one 'forest' category; all other land cover types including plantations were classed as 'non-forest'. Our survey teams visited all areas, and were thus able to ground-truth the imagery. This ground-truthing included the 133 dung survey transects (totalling 285.94 km) in BBSNP and WKNP. In addition, we used the analysis of Kinnaird et al. (2003) for deforestation patterns in BBSNP. Image processing and analysis were carried out using ERDAS Imagine (version 8.4, from ERDAS, GA, USA) and Arcview 3.2 and ARC/INFO 7.2 (Environmental Systems Research Institute, CA, USA).

2.4. Direct threats to wild elephants: poaching and elephant capture operations

Elephant mortality data were gathered opportunistically during field surveys and collated from unpublished reports, including those of WWF-Indonesia and the Indonesian Rhino Conservation Program's Rhino Protection Units (RPUs) and Tiger Protection Units (TPUs). We collated data on the numbers of elephants captured in Lampung from the Provincial Natural Resource Conservation Agency office (BKSDA–Lampung), the ETC in WKNP, the International Elephant Foundation (IEF), and local informants.

2.5. Human–elephant conflict

We trained staff from an Indonesian NGO (WATALA) in crop damage assessment techniques, and these 'Problem Animal Recorders' (PARs) recorded all crop losses to elephants reported from agricultural areas adjacent to BBSNP and WKNP. To enable the PARs to assess crop damage without relying on the farmers' estimates, we developed a protocol for quantifying crop damage that involved the PARs mapping crop fields and areas of damaged crops using topofils and sighting compasses (Sitompul, 2004). Our PARs also recorded the number of elephants involved (during interviews with farmers), and collected planting and harvest times from villagers. Information on the location of crop-raiding

incidents was gathered during the PARs' regular patrols around the parks' perimeters, and from a network of local informants that the PARs had established to keep them informed of human–elephant conflict incidents. We also collected data on the market values of crops as well as all reported losses to agricultural pests from the provincial government's agricultural service.

3. Results

3.1. Elephant distribution

Of the 12 areas of Lampung that had elephant population in the early 1980s, only BBSNP, WKNP, and the Gunung Rindingan–Way Waya complex (GRWW) still had resident populations in 2002 (Table 1 and Fig. 1). The elephants in GRWW occur in an area of dissected terrain with relatively intact forest, and isolated hills surrounded by agriculture. We conducted 38.77 km of 'recce' transects in the Sendang and Batu Tegi areas of GRWW but found no dung-piles, although a few elephant footprints were found. We found four dung-piles during 36.01 km of 'recce' transects in the nearby Gunung Rindingan area, suggesting that elephants may be crossing between these forest blocks. Dung-pile density was too low for dung-based estimates of elephant population size to be calculated for the GRWW area. However, a group of 12–17 elephants was reportedly seen in this area by forest officials in 2000, and groups of 3–6 elephants raided crops in the area in early 2002.

We found no evidence of elephants in the Gunung Sulah, Gunung Betung/Gunung Pesewaran, and Pematang Kubuatu/Gunung Tanggang Protection Forests on the central southern peninsula. These areas are now largely under agriculture. According to earlier reports (Santiapillai and Ramono, 1993; Tilson et al., 1994), the elephant populations in these areas had already been extirpated as a result of elephant capture operations by 1990. Our data support this for two of the sites, but local people told us that a few elephants were present until 1996 in the Pematang Kubuatu/Gunung Tanggang area.

We found no evidence of elephants in the Way Terusan/Tulang Bawang area. The area is now under sugar cane plantations and shrimp farms. According to local informants, elephants occurred until 1999 or 2000, when it is believed the last four were caught.

None of the Production Forests blocks within the *Translok* resettlement area of North Lampung (blocks 42, 44, 45, and 46; Table 1 and Fig. 1) contained any elephants in 2002. These areas have been converted to agriculture and settled, and there is no longer any forest cover. The small area of degraded Protection Forest in the Bukit Saka area of North Lampung did not appear to hold any elephants in 2002. However, a large area of apparently intact forest over the border in Sumatera Selatan Province may still contain elephants since local people reported seeing them there in 2000.

3.2. Elephant abundance

We found a total of 1313 elephant dung-piles along 58 line transects with total length 73.63 km in BBSNP. Mean encounter rates were and 25.44 and 1.29 dung-piles per km in the high and low-density strata, respectively. To estimate elephant density, we used a mean defecation rate of 18.15 defecations per 24 h (CV = 13.94%) derived from our study of free-ranging elephants in WKNP (Tyson et al., 2002), and disappearance rate data for 1302 dung-piles monitored from July 2000 to November 2001 in BBSNP. Analysis of these data using the DUNGSURV program gave an estimated dung-pile duration of 305.36 days (CV = 2.4%). Our analyses of these data using the program DISTANCE produced estimates of 0.57 (CV = 15.39%) and 0.03 (CV = 41.59%) elephants per km^2 for the high and low density strata, respectively. Based on our estimates of the extent of suitable elephant habitat in BBSNP (773 and 1938 km^2 in the high and low density strata, respectively), we calculated an area-weighted mean density of elephants of 0.18 individuals per km^2 (CV = 14.57%). This gave an overall population estimate of 498 (95% CI = [373, 666]) elephants in BBSNP in 2001.

We found 1093 dung-piles along 80 line transects with total length 212.31 km in WKNP. Mean encounter rates were 6.77 and 1.55 dung-piles per km in the high and low-density strata, respectively. We used data on dung disappearance rates for 4881 dung piles monitored in WKNP between June 2000 and March 2002. Analysis of these data using the DUNGSURV program gave an estimated dung-pile duration of 459.84 days (CV = 1.3%) in the low density stratum (grassland and scrub) and 231.5 days (CV = 1.9%) in the high density stratum (secondary forest). We used a defecation rate of 18.15 defecations per 24 h (CV = 13.94%). Our analyses of these data using the program DISTANCE produced estimates of 0.24 (CV = 10.40%) and 0.03 (CV = 20.04%) elephants per km^2 in the high and low density strata, respectively. Using our estimates of the extent of suitable elephant habitat (694 and 541 km^2 in the high and low density strata, respectively), these data yield an area-weighted estimate of 180 (95% CI = [144, 225]) elephants in WKNP in 2002.

3.3. Habitat condition

Satellite imagery for the 12 areas that contained elephant populations in the mid 1980s shows that forest cover in these areas declined from 5694 to 2219 km^2 in 2000. Seven areas have been completely, or almost completely, deforested and are now under agriculture, plantations, and settlements (Table 1 and

Table 1
Sites in Lampung Province believed to hold elephants in the mid-1980s and elephant occurrence in 2002

Name of area (and land registry number)	No. on Fig. 1	Regency (*Kabupaten*)	Area of forest in 1985/86 (ha)	Area of forest in 2000 (ha)	Legal status of area in 2002/ current land use	Reported elephant population size in '84 and '93	Actions recommended at 1993 PHVA workshop	Elephants captured in area?	Elephants known to occur in 2002?	Elephants last reported	Human–elephant conflict in 2002?
Bukit Barisan Selatan National Park (reg. 22B, 49B, 46B, 47B, & 49)	1	West Lampung	187,100	120,920 (1999 data)	National Park/ forest, scrub, grassland, and illegal cultivation	150–200+ (84) >200 (93)	Monitoring	Yes	Yes, 498 (95% CI [373,666])	2002	Yes
Bukit Saka (Lampung part of Gunung Raya region) (reg. 41)	2	North Lampung (within *Translok* resettlement area)	1200	0	Protected forest/ scrub	50–100 (84) 60 (93)	Protection and habitat improvement	Yes	No, maybe in Sum. Sel.	2000	No
Block 42 (reg. 42)	3	North Lampung (within *Translok* resettlement area)	13,510	0	Converted Prod. Forest/scrub, settlements, and agriculture	<50 (84) 30 (93)	Assess alternatives to planned capture of all elephants	Yes? (see text)	No	1993	No
GRWW complex (Gunung Rindingan Tangkit Cumbi/ Tebak Way Waya/Batu Tegi region; reg. 22, 32, and 34)	4	North, Central, South, and West Lampung	43,075	24,295	Protected Forest/ forest, scrub, and agriculture	50–100 (84) 50–100 (93)	Protection and habitat improvement	Yes	Yes, small popultn prob. >17	2002	Yes
Block 46 (reg. 46)	5	North Lampung (within *Translok* resettlement area)	20,195	0	Converted Prod. Forest/plantations, settlements, and agriculture	50–100 (84) 20 (93)	Assess alternatives to planned capture of all elephants	Yes? (see text)	No	1993	No

Block 44 (reg. 44)	6	North Lampung (within *Translok* resettlement area)	32,375	0	Converted Prod. Forest/agriculture and settlements	50–100 (84) 20 (93)	Assess alternatives to planned capture of all elephants	Yes	No	1994	No
Block 45 (Air Mesuji) (reg. 45)	7	North Lampung (within *Translok* resettlement area)	43,100	0	Converted Prod. Forest/agriculture, settlements, and forestry plantations	>100 (84) 110 (93)	Assess alternatives to planned capture of all elephants	Yes	No	1997	No
Way Terusan/ Tulang Bawang (reg. 47)	8	North Lampung	105,000	4564	Converted Prod. Forest/sugar cane plantations, shrimp farms, and forest	50–100 (84) 40 (93)	Assess alternatives to planned capture of all elephants	Yes	No	2000	No
Way Kambas National Park (reg. 9)	9	Central Lampung	78,726	68,842	National Park/ forest, scrub, grassland, and illegal cultivation	50–100 (84) 200–250 (93)	Monitoring	Yes	Yes, 182 (95% CI [144,225])	2002	Yes
Gunung Sulah (reg. 21 and 27)	10	South Lampung	15,122	488	Protected Forest/ scrub, agriculture and forest	<50 (84) 0 (93)	None (population already extinct)	Yes	No	1990	No
Gunung Betung/ Gunung Pesewaran (reg. 19)	11	South Lampung	22,244	2080	Protected Forest/ plantations, agriculture, forest	<50 (84) 0 (93)	None (population already extinct)	Yes	No	1987	No
Pematang Kubuatu/ Gunung Tanggang (reg. 20 and 25)	12	South Lampung	7780	732	Protected Forest/ agriculture and forest	<50 (84) 0 (93)	None (population already extinct)	Yes	No	Before 1990 (but see text)	No

1. Forest block names, land register numbers, and current legal status: all data obtained from the Provincial Natural Resource Conservation Agency office (BKSDA–Lampung). 2. Regency (*Kabupaten*) names are those used in the 1980s; for ease of comparison recent name and boundary changes are ignored. 3. Forest areas were calculated from LANDSAT Thematic Mapper satellite images for 1983–86 and 2000, for further detail about BBSNP see Kinnaird et al. (2003). 4. Reported elephant population sizes for 1984 and 1993 were obtained from Blouch and Haryanto (1984) and Tilson et al. (1994), respectively. 5. The actions recommended at the 1993 Sumatran Elephant Population and Habitat Viability Analysis (PHVA) Workshop are discussed in more detail in Tilson et al. (1994). 6. Sources of elephant capture data are as described in the main text. 7. All other data were collected during our surveys, as described in the main text.

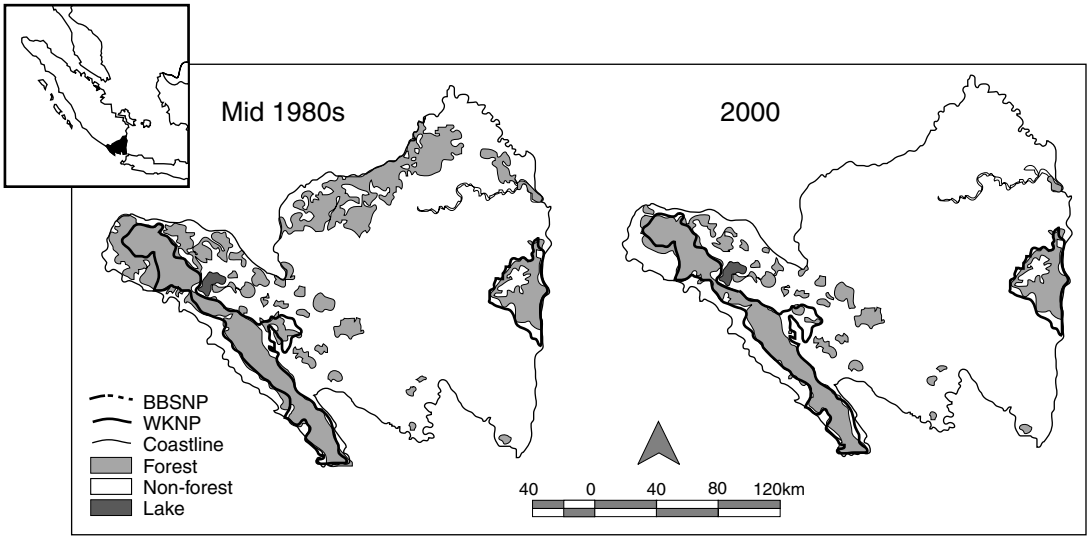

Fig. 2. Changes in forest cover in Lampung Province over the mid 1980s to 2000 period.

Fig. 2). Forest cover in WKNP declined from 787 km^2 in the mid 1980s to 688 km^2 in 2000 (Table 1). Much of this loss is thought to have been due to fires, which were particularly severe in 1994 and 1997/98 (Asian Development Bank, 1999; Levine et al., 1999; Barber and Schweithelm, 2000). For BBSNP, Kinnaird et al. (2003) reported that between 1985 and 1999, forest loss averaged 2% per year with a total of 661 km^2 disappearing from the park.

3.4. Direct threats to wild elephants: poaching and elephant capture operations

We documented the deaths of 22 elephants in BBSNP and nine elephants in WKNP between 1 January 2000 and 1 November 2002. These figures represent minimum estimates because no dedicated carcass searches were conducted. Of the 22 animals in BBSNP, two apparently died as a result of human–elephant conflict but most of the others are thought to have been killed by poachers. Unpublished TPU reports indicate that poachers in the BBSNP area may have killed another 14 elephants during this time, but these reports were not verified. One of the nine elephants found dead in WKNP was shot by park staff because it was threatening a village close to the park, but the causes of death of the remaining eight are unknown.

We determined that elephants were captured by the government in the 1980s and 1990s in all forest blocks known to contain elephants in the 1980s, with the possible exception of blocks 42 and 46 (Table 1). We cannot be certain that elephants were caught in these two blocks because the government's detailed site records are reportedly missing. Nevertheless, it is likely that captures occurred given the number of elephants listed as caught in North Lampung in the more general reports (Table 2), and the fact that government policy for these two sites was to catch all elephants (Tilson et al., 1994). Between 1984 and 1996, government records show 298 elephants were captured in Lampung. These figures are likely to be underestimates, because elephant deaths during capture operations are routinely under-reported or completely excluded from official reports. From 1997 to 2002, the data are incomplete, but at least 37 elephants were captured in the province (Table 2). Three populations in South Lampung had been completely extirpated as a result of capture operations prior to 1990 according to Santiapillai and Ramono (1993, Table 1, but see Section 3.1). Our results suggest that a further four populations, all in North Lampung, had been extirpated largely if not solely as a result of capture operations by 2000 (Table 1).

3.5. Human–elephant conflict

We investigated 340 crop damage incidents around BBSNP and 377 crop damage incidents around WKNP between June 2000 and September 2002. We conducted 1197 interviews with farmers in 47 villages in or adjacent to the non-park forest blocks where elephants were previously reported. We received reports of crop raiding in two villages near the GRWW forest complex in 2002, but there were no reports of human–elephant conflict for any of the other non-park areas (Table 1). Of the crop raiding incidents adjacent to BBSNP, 200 occurred between January and May 2002 due to two persistent groups of elephants. The remaining 140 incidents occurred primarily along park boundaries in areas of high human encroachment, and were not consistently associated with areas of high elephant density within the park. In WKNP, crop raiding occurred along the park's boundaries in areas adjacent to both high and low ele-

Table 2
Elephant captures in Lampung Province 1984–2002, by Kabupaten (sources: BKSDA–Lampung, Elephant Training Center at WKNP, and IEF; post-1997 data are believed incomplete)

Year	North	South	Central	West	Total
1984	0	0	1	0	1
1985	8	0	3	0	11
1986	4	2	8	0	14
1987	14	1	11	0	26
1988	15	5	6	0	26
1989	10	0	2	0	12
1990	3	0	6	0	9
1991	2	8	1	0	11
1992	4	0	2	0	6
1993	16	1	5	0	22
1994	25	1	7	0	33
1995	23	0	9	2	34
1996	42	5	21	25	93
1997	8	–	1	–	9
1998	4	2	11	4	21
1999	–	1	5	–	6
2000	–	–	–	–	–
2001	–	–	–	1	–
2002	–	1	–	–	1
Total	178	25	100	32	335

phant density within the park. For the June 2000 to May 2002 period, elephants destroyed 20 houses, killed two people, and permanently disabled another person in the BBSNP area; while in the WKNP area elephants destroyed one house, killed one person and permanently disabled two others.

For the 20 villages around WKNP that had elephant problems between June 2000 and May 2002, the direct financial loss due to crop raiding was approximately US$12,000. The maximum loss for a single village was about US$2000. These figures are based on the market value of damaged or consumed crops only. No attempt was made to calculate opportunity costs associated with human–elephant conflict (e.g. opportunities for farmers' family members to earn money that are lost because they are guarding crops). In 2000, agricultural service data for six districts around BBSNP show that insects and rodents damaged 7388 and 1635 ha of rice, respectively, the equivalent figures for 2001 were 6344 and 1092 ha, respectively. For these same districts agricultural service data show that elephants damaged just 30 and 20 ha of rice in 2000 and 2001, respectively.

4. Discussion

4.1. Status of Asian elephant populations in Lampung in 2002

Our data show that only 3 of 12 elephant populations known to occur in Lampung in the early 1980s were extant in 2002. Moreover, our data indicate that the GRWW population may be too small to be viable over the long-term. Tilson et al. (2001) found a similar situation for tigers in Lampung. Our estimate of 498 (95% CI = [373, 666]) elephants in BBSNP is much larger than the previous figure of 200 reported by Blouch and Haryanto (1984). Our estimate of 180 (95% CI = [144, 225]) elephants in WKNP falls between prior estimates, which ranged from a low of 30 elephants in the 1970s (UNDP/FAO, 1979) to a high of 569 in 1994 (Reilly, 2002a), and is closest to the estimate provided by Santiapillai and Suprahman (1986), who suggested that there were 260–350 elephants in WKNP in 1986.

We believe that these differences in population estimates reflect differences in survey methods. Blouch and Haryanto (1984) relied primarily on interviews and brief field trips to derive their elephant numbers, and they acknowledged that their estimates were informed guesses. Santiapillai and Suprahman (1986) derived their estimate for WKNP from elephant densities reported from other locations and these densities were themselves based on extrapolations, rather than sampling-based survey methods. Although Reilly used field methods similar to ours, her data sets were small and seasonally limited. Furthermore, we believe that the methods she used to analyse her data were inappropriate, and may have led her to overestimate the size of the WKNP elephant population. Specifically, while the defecation rates used by Reilly were appropriate for the periods for which they were calculated (i.e. 11.83 and 13.04 defecations per 24 h in the dry seasons of 1994 and 1997,

respectively, both of which were ENSO related drought years in Lampung), we believe they are unlikely to have been appropriate for the non-drought period over which many of the dung-piles found on her transects would have accumulated. We suspect that the defecation rate for much of the dung-pile accumulation period would have been closer to the 18.15 defecations per 24 h used in the present study, and consequently we believe that use of the much lower defecation rates would have led to a significant overestimates of elephant density in WKNP. Furthermore, Reilly used the 'steady state' model of McClanahan (1986) and Barnes and Jensen (1987) to estimate elephant density. This model assumes constant defecation and dung disappearance rates, but because Reilly's survey periods overlapped but were not restricted to ENSO-related drought months, these assumptions are unlikely to have been met – indeed it is extremely unlikely that dung-pile decay rates would remain constant for a period that includes both drought and non-drought periods given that rainfall is widely recognized as a major factor affecting decay rates (White, 1995; Barnes et al., 1997; Nchanji and Plumptre, 2001).

Given these problems with Reilly's methods, our estimates for BBSNP and WKNP are the first for Southeast Asian elephant populations to be based on rigorous sampling-based methods, which satisfied the assumptions of the models used. Previous attempts to estimate elephant population size elsewhere in Southeast Asia have relied on a combination of guesswork, brief reconnaissance trips, non-standard methods that have never been subject to peer review, or dung-counts based on assumptions that were not demonstrably valid at the time of the survey (Duckworth and Hedges, 1998; Blake and Hedges, 2004). Our results suggest that elephant numbers in these parks are of regional, and for BBSNP, international importance. While the loss of nine of Lampung's elephant populations is regrettable, the continued presence of two important populations in such a densely populated province is remarkable. The challenge now is to protect these populations from further habitat loss and poaching, and to better manage human–elephant conflict.

4.2. The decline of Lampung's elephant populations: proximate and ultimate causes

The proximate cause of elephant extirpation in most areas between 1984 and 2002 was the Indonesian Government's policy of capturing elephants to reduce human–elephant conflict. In some areas, notably around BBSNP and WKNP, this human–elephant conflict manifested itself as chronic crop-raiding by wild elephants temporarily leaving the protected areas. However, in most cases, conflict was more acute as people appropriated elephant habitat, and the majority of elephants captured in Lampung were caught because they occurred in Production Forests that were scheduled for conversion to agriculture and settlements (Tilson et al., 1994; Lair, 1997). Thus the ultimate cause of the decline was habitat loss.

In 1993, a Sumatran Elephant Population and Habitat Viability Analysis (PHVA) Workshop was held in Lampung (Tilson et al., 1994). By this time, three elephant populations in South Lampung had already been extirpated as a result of elephant capture operations, and another five were scheduled for complete removal because they were in Production Forests that were being converted to agriculture and settlements (Tilson et al., 1994; Table 1). Although Tilson et al. recommended an assessment of the status of those elephant populations scheduled for capture, as well as an assessment of whether elephant drives or translocations would be feasible alternatives to capturing elephants, neither of these recommendations were followed. The loss of all but one of Lampung's elephant populations outside of the two parks reduced levels of human–elephant conflict in the province, but elephants continued to be caught from the parks as a result of crop raiding. Capture rates fell dramatically, however, as a result of the Asian financial crisis (which began in 1997), and few elephants have been caught in Lampung since 1998 (Table 2).

4.3. Current threats to the elephant populations in Lampung

We believe habitat loss will be the main threat to Lampung's elephants over the next decade. Kinnaird et al. (2003) suggest that by 2010, 70% of BBSNP will be under agriculture and nearly all forest on gentle slopes at low elevations will be eliminated. In WKNP, ongoing loss of forest to illegal logging and fires is being compounded by agricultural encroachment. Without effective protection for these national parks it seems inevitable that their elephant populations will be lost. Furthermore, as agricultural encroachment expands it is likely that human–elephant conflict will increase in and immediately around the parks, which may lead to a resumption of large-scale elephant catching or possibly the direct killing of elephants by farmers.

While the killing of elephants for sport or ivory and other body parts has not been a major threat to Sumatra's elephants since they were given full legal protection in 1931 (Santiapillai and Jackson, 1990), there are indications that illegal killing of elephants is increasing in Sumatra. Anecdotal evidence suggests that elephants have been targeted for their ivory and other body parts in recent years, whereas earlier they were primarily killed in retaliation for crop raiding (Lair, 1997; Sitompul et al., 2002). Furthermore, over the last few years iv-

ory has been more frequently available in local markets, including those near BBSNP (authors' personal observations, 2000–2004).

4.4. Actions required to conserve Asian elephants in Lampung

4.4.1. Survey and monitoring needs

Knowledge of population levels and trends is fundamental to the management of endangered species and consequently there is a clear need to monitor the elephant populations in BBSNP and WKNP, either using methods similar to those of the present study or other sampling-based methods. Poaching of Asian elephants can lead to strongly skewed population sex ratios (Sukumar, 1992), and so monitoring programs for elephant populations should attempt to assess age- and sex-structure. Conventional dung-count surveys cannot provide this level of resolution but age-structure can be determined from the dimensions of dung boli (Jachmann and Bell, 1984; Reilly, 2002b), and estimates of population size and sex structure can be derived from faecal DNA (Eggert et al., 2003). These methods should be considered for future elephant surveys in Lampung and elsewhere on Sumatra.

There is a clear need for a Sumatra-wide survey to determine how many of the elephant populations identified by Blouch and Haryanto (1984) and Blouch and Simbolon (1985) are still extant. Given that 75% of Lampung's elephant populations have been lost since 1984, it is likely that a significant number of populations in other provinces have also been lost.

4.4.2. Reducing the illegal killing of elephants

Our work shows that that illegal killing of elephants is a major threat to both populations. Regular dedicated carcass searches are needed to further quantify the problem. The current low detection rate for carcasses, the lack of arrests in relation to elephant poaching, and the existence of local ivory markets clearly imply that existing anti-poaching efforts are inadequate as an effective deterrent to poachers.

There has been no research in Indonesia to assess the efficacy of various deterrents to poachers. However, research in the Luangwa Valley in Zambia showed that frequent foot-patrols reduced poaching (Leader-Williams et al., 1990). The members of the Luangwa law enforcement units spent about half of each month patrolling, even in remote areas and under difficult conditions. It was further suggested that full protection of vulnerable target species such as elephants and rhinoceroses required one guard per 20 km^2 of protected area. By contrast, the number of patrol days by RPUs in Sumatra has been consistently below the target of 20 days/month. An average of 9.8, 12.7, and 11.3 days/month were spent in BBSNP in 1999, 2000, and 2001 respectively; and for WKNP the figures were 10.3, 10.8, and 9.8 respectively (Hutabarat et al., 2002). More importantly, the Indonesian government allocates too few patrol staff to provide adequate protection for the high profile species in Sumatra's conservation areas. In BBSNP and WKNP, there are 66 and 87 Forest Police respectively, but few of these men spend much time on patrol and the RPUs and TPUs provide the only regular patrols. However, approximately 36 men from the RPUs and TPUs are responsible for patrolling approximately 1950 km^2 of BBSNP and about 23 men are responsible for about 833 km^2 of WKNP – or only 37% (BBSNP) and 54% (WKNP) of the staffing levels recommended by Leader-Williams et al. (1990).

The major challenge in Lampung and other parts of Sumatra is to facilitate the deployment of motivated and adequately equipped foot patrols in sufficient numbers to protect elephants and other species. In order to reduce the manpower and other resources needed to attainable levels, core zones that support particularly important sub-populations of key species should be identified from field surveys such as those reported here. This approach to patrolling core zones has met with success in other parts of Asia (e.g. Mishra et al., 1987; Karanth, 1991, 1998). In India, success is highest in areas where local intelligence networks have been created and clear and specific anti-poaching plans are made (Duckworth and Hedges, 1998; Karanth, personal communication).

4.4.3. Addressing human–elephant conflict

Crop-raiding by elephants is a chronic problem around BBSNP and WKNP (Nyhus et al., 2000; this study). Previous attempts to reduce crop-raiding have met with limited success. For example, a canal designed to keep elephants out of agricultural areas around the park fell into disrepair because streams and wetlands eroded the canal's banks (Nyhus et al., 2000). Chronic crop-raiding leads to feelings of resentment directed at elephants (Hart and O'Connell, 2000; O'Connell-Rodwell et al., 2000; Zhang and Wang, 2003; cf. Bandara and Tisdell, 2003). Farmers consequently put pressure on government agencies to catch elephants, and in some cases they take the law into their own hands and kill elephants. Human–elephant conflict is thus a direct threat to wild elephant populations. In recognition of the need to implement an effective human–elephant conflict mitigation strategy and demonstrate alternatives to catching elephants, we are working with farmers, park officials, local NGOs, and government staff to test a number of low-cost deterrent methods around WKNP.

Our data show that the value of crops damaged or eaten by elephants in Lampung is relatively small,

particularly when compared to the impact of other agricultural pests. An earlier interview-based study of crop-raiding around WKNP by Nyhus et al. (2000) did not provide estimates for the cash value of crops lost, but did suggest that raiding rates were significantly higher than indicated by our work. Specifically, over a 24-month period (2000–2002) we found the number of incidents around Way Kambas was seven times lower than reported by Nyhus et al. for 1996–1997. It is possible that raiding rates have dropped, but local farmers do not support this idea. It is more likely that the farmers over-reported the size of the problem when interviewed in 1996–1997, possibly in an attempt to elicit action from the government.

Knowing the true cost of human–elephant conflict is essential when planning appropriate mitigation strategies. We suspect that the cost of capturing elephants and maintaining them in the ETCs exceeds the cost of establishing coordinated crop-guarding schemes like those we initiated around WKNP. There is clearly a need, therefore, to assess the relative costs of human–elephant conflict and the different mitigation methods in Sumatra.

4.4.4. Protecting elephant habitat

Immediate and effective action is required if elephants are to survive in Sumatra's forests, including those in BBSNP and WKNP. A priority for both parks is to stabilize boundaries and stop encroachment. Enforcement of existing laws to prevent land clearance, the setting of fires, and timber theft would reduce disturbance to elephants and other wildlife, and help prevent habitat deterioration (Kinnaird et al., 2003). In addition, habitat restoration and voluntary resettlement from inhabited areas within the parks should be considered. These recommendations may be "generic", but that does not mean such actions are unnecessary. Indeed, they rank among the top priority actions needed to safeguard the parks' elephant populations.

These needs have long been recognized, but effective solutions have so far eluded Indonesia's conservation agencies and the international conservation community (Sunderlin, 1999; McCarthy, 2000; Jepson et al., 2001). Part of the solution to these complex multi-sectoral problems lies in increased funding for forest protection and other conservation initiatives. Sumatra has attracted the attention of major nongovernmental organizations (NGOs), including the Wildlife Conservation Society, WWF, Fauna & Flora International, and Conservation International. All of these NGOs are funding projects that aim to protect the forest habitat of elephants and other high priority species on Sumatra. Multi-lateral donors, including the World Bank, the Global Environment Facility, and the European Union are also active in Sumatra. Unfortunately, the funds from these organizations, multi-lateral donors and NGOs alike, have not always been spent wisely (Wells et al., 1999; Whitten et al., 2001). More importantly, there are unlikely to be significant improvements in the management of Indonesia's natural resources without profound changes in the socio-political climate in Indonesia. If the Indonesian Government does not address corruption, social unrest, lawlessness, and bureaucratic inertia as a matter of urgency, the future for Sumatra's forests and the elephants and other wildlife that depend on them will be bleak.

Acknowledgements

Our research was a collaborative effort by the Wildlife Conservation Society's Indonesia Program and the Indonesian Ministry of Forestry's Directorate General of Forest Protection and Nature Conservation (PHKA). The work was funded by the Wildlife Conservation Society, the US Fish and Wildlife Service (through the Asian Elephant Conservation Fund, grants 1448-98210-00-G496, 98210-1-G806, and 98210-2-G292), the National Geographic Society (grant 7060-01), and WWF-US. The satellite interpretation and geographic analysis were supported by software donations from the Environmental Systems Research Institute Conservation Program. Conservation International generously provided satellite images of Lampung for 2000. We are grateful to all these organizations. We thank Joshua Ginsberg, Penny Kalk, Billy Karesh, Rob Lee, Tim O'Brien, Eric Sanderson, and Karl Stromayer for their support and advice during the project. The work would not have been possible without the willingness of the WCS Sumatran Elephant Project's numerous staff to work under what were sometimes trying circumstances. We are very grateful to them all. We would also like to acknowledge our colleagues from WATALA and the staff of PHKA, especially those in Bukit Barisan Selatan and Way Kambas National Parks. Additional thanks are due the following people for providing information about the distribution, status, and capture of elephants: Rudy Akbarta, Bintoro, Susan Canney, Nancy Drilling, Melanie Faith Dove, Hank Hammatt, Muhammad Iqbal, Budi Jatmika, Paul Jepson, Frank Lambert, Barita Manullang, Debbie Martyr, Susan Mikota, Meyner Nusalawo, Debbie Olson, Dolly Priatna, Andjar Rafiastanto, Joanne Reilly, Heidi Riddle, Joko Santoso, Michael Stüwe, Sudarmadji, Sukatmoko, Philip Wells, and Hariyo Wibisono. Finally, we thank Tiffany Passmore for preparing the maps, and Joshua Ginsberg, Hank Hammatt, Tim O'Brien, and two anonymous reviewers for their constructive comments on the manuscript.

References

Adhiati, M.A.S., Bobsien, A., (Eds.), 2001. Indonesia's Transmigration Programme – An Update. A report prepared for Down To Earth, London, UK.

Asian Development Bank, 1999. Causes, Extent, Impact and Costs of 1997/1998 Fires and Drought. Final report, Annex 2. Planning for Fire Prevention and Drought Management Project. Asian Development Bank TA 2999-INO, Jakarta, Indonesia.

Bandara, R., Tisdell, C., 2003. Comparison of rural and urban attitudes to the conservation of Asian elephants in Sri Lanka: empirical evidence. Biological Conservation 110, 327–342.

Barber, C.V., Schweithelm, J., 2000. Trail by Fire: Forest Fires and Forestry Policy in Indonesia's Era of Crisis and Reform. World Resources Institute, Washington, DC, USA.

Barnes, R.F.W., Jensen, K.L., 1987. How to count elephants in forests. IUCN/SSC African Elephant and Rhino Specialist Group Technical Bulletin No. 1.

Barnes, R.F.W., Asamoah-Boateng, B., Naada Majam, J., Agyei-Ohemeng, J., 1997. Rainfall and the population dynamics of elephant dung-piles in the forests of southern Ghana. African Journal of Ecology 35, 39–52.

Benoit, D., Levang, P., Pain, M., Sevin, O., 1989. Transmigration Et Migrations Spontanees En Indonesie: Propinsi Lampung. Departemen Transmigrasi, Jakarta, Indonesia and ORSTOM, Bondy, France.

Blake, S., Hedges, S., 2004. Sinking the flagship: the case of forest elephants in Asia and Africa. Conservation Biology 18, 1191–1202.

Blouch, R.A., Haryanto, 1984. Elephants in Southern Sumatra. Unpublished report, IUCN/WWF Project 3033, Bogor, Indonesia.

Blouch, R.A., Simbolon, K., 1985. Elephants in Northern Sumatra. Unpublished report, IUCN/WWF Project 3033, Bogor, Indonesia.

Bowen, M.R., Borger, B.H., 2001. Biodiversity loss in Sumatra, Indonesia. Vegetation fires: cause or symptom?. In: Proceedings of the Workshop on Minimizing the Impact of Forest Fire on Biodiversity in ASEAN, Brunei Darussalam, 22–23 March 2001. ASEAN Regional Centre for Biodiversity Conservation (ARCBC) and the Government of Brunei, Darussalam.

Buckland, S.T., Andersen, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, UK.

Duckworth, J.W., Hedges, S., 1998. Tracking Tigers: A review of the Status of Tiger, Asian Elephant, Gaur, and Banteng in Vietnam, Lao, Cambodia, and Yunnan (China), with Recommendations for Future Conservation Action. WWF Indochina Programme, Hanoi, Vietnam.

Eggert, L.S., Eggert, J.A., Woodruff, D.S., 2003. Estimating population sizes for elusive animals: the forest elephants of Kakum National Park, Ghana. Molecular Ecology 12, 1389–1402.

Fearnside, P.M., 1997. Transmigration in Indonesia: lessons from its environmental and social impacts. Environmental Management 21, 553–570.

Fleischer, R.C., Perry, E.A., Muralidharan, K., Stevens, E.E., Wemmer, C.M., 2001. Phylogeography of the Asian elephant (*Elephas maximus*) based on mitochondrial DNA. Evolution 55, 1882–1892.

Foose, T.J., van Strien, N., 1997. Asian Rhinos – Status Survey and Conservation Action Plan. IUCN, Gland, Switzerland and Cambridge, UK.

Franklin, N., Bastoni, Sriyanto, Siswomartono, D., Manansang, J., Tilson, R., 1999. Last of the Indonesian tigers: a cause for optimism. In: Seidensticker, J., Christie, S., Jackson, P. (Eds.), Riding the Tiger: Tiger Conservation in Human-dominated Landscapes. Cambridge University Press, Cambridge, UK, pp. 130–147.

Groeneveldt, W., 1938. Een overzicht van de vaste trekwegen van olifanten in Zuid Sumatra alsmede eenigegegevens over rhinocerossen. Nederlandsche Commissie voor Internationale Natuurbescherming, Mededeelingen 12, pp. 73–109.

Hart, L.A., O'Connell, C.E., 2000. Human conflict with African and Asian elephants and associated conservation dilemmas. Unpublished Paper. Center for Animals in Society in the School of Veterinary Medicine and Ecology, University of California, Davis 95616, USA.

Hiby, L., Lovell, P., 1991. DUNGSURV – a program for estimating elephant density from dung density without assuming steady state. In: Ramakrishnan, U., Santosh, J., Sukumar, R. (Eds.), Censusing Elephants in Forests: Proceedings of an International Workshop. Asian Elephant Conservation Centre, Bangalore, India.

Hutabarat, A.A., Subrata, D.D., van Strien, N., 2002. Indonesian Rhino Conservation Program: Annual Report 2001, July 2002. Unpublished report, Indonesian Rhino Conservation Program and International Rhino Foundation, Bogor, Indonesia.

IUCN–The World Conservation Union, 2004. 2004 IUCN Red List of Threatened Species. On the World Wide Web: http://www.redlist.org (accessed on 6 December 2004).

Jachmann, H., Bell, R.H.V., 1984. The use of elephant droppings in assessing numbers, occupance, and age structure: a refinement of the method. African Journal of Ecology 22, 127–141.

Jepson, P., Jarvie, J.K., MacKinnon, K., Monk, K.A., 2001. The end for Indonesia's lowland forests?. Science 292, 859–861.

Karanth, K.U., 1991. Ecology and management of the Tiger in tropical Asia. In: Maruyama, N., Bobek, B., Ono, Y., Reglin, W., Bartos, L., Ratcliffe, R. (Eds.), Wildlife Conservation: Present Trends and Perspectives for the 21st Century. Japan Wildlife Research Centre, Tokyo, Japan, pp. 156–159.

Karanth, K.U., 1998. Sacred groves for the 21st century. Seminar 466, 25–31.

Kemf, E., Santiapillai, C., 2000. Asian Elephants in the Wild: A WWF Species Status Report. WWF – World Wide Fund for Nature, Gland, Switzerland.

Kinnaird, M.F., Sanderson, E.W., O'Brien, 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.

Lair, R.C., 1997. Gone Astray: The Care and Management of the Asian Elephant in Domesticity. FAO, Rome, Italy.

Leader-Williams, N., Albon, S.D., Berry, P.S.M., 1990. Illegal exploitation of Black rhinoceros and elephant populations: patterns of decline, law enforcement and patrol effort in Luangwa Valley, Zambia. Journal of Applied Ecology 27, 1055–1087.

Levang, P., 1997. La Terre D'en Face. La Transmigration En Indonésie. ORSTOM, Paris, France.

Levang, P., Yoza, B.K., Etty, D., Etty, H., 1999. Not every cloud has a silver lining: crop farmers in transmigration areas. ACIAR Indonesia research project, working paper 99.16, CIES, University of Adelaide, Australia.

Levine, J.S., Bobbe, T., Ray, N., Witt, R.G., Singh, A., 1999. Wildland Fires and the Environment: A Global Synthesis. Environmental Information and Assessment Technical Report UNEP/DEIA & EW/TR.99-1. United Nations Environment Programme, Nairobi, Kenya.

McCarthy, J.F., 2000. 'Wild Logging': The Rise and Fall of Logging Networks and Biodiversity Conservation Projects on Sumatra's Rainforest Frontier. CIFOR Occasional Paper No. 31, Center for International Forestry Research, Bogor, Indonesia.

McClanahan, T.R., 1986. Quick population survey method using faecal droppings and a steady state assumption. African Journal of Ecology 24, 37–39.

McNeely, J.A., 1978. Management of elephants in Southeast Asia. In: McNeely, J.A. et al. (Eds.), Wildlife Management in Southeast Asia. BIOTROP, Bogor, Indonesia, pp. 219–225.

Mishra, H.R., Wemmer, C., Smith, J.L.D., 1987. Tigers in Nepal: management conflicts with human interests. In: Tilson, R.L., Seal, U.S. (Eds.), Tigers of the World: the Biology, Biopolitics, Management and Conservation of an Endangered Species. Noyes Publications, New Jersey, USA, pp. 449–463.

Nchanji, A.C., Plumptre, A.J., 2001. Seasonality in elephant dung decay and implications for censusing and population monitoring in south-western Cameroon. African Journal of Ecology 39, 24–32.

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'Brien, T.G., Wibisono, H.T., Kinnaird, M.F., 2003. Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. Animal Conservation 6, 131–139.

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.

Plumptre, A.J., 2000. Monitoring mammal populations with line transect techniques in African forests. Journal of Applied Ecology 37, 356–368.

Reilly, J., 2002a. The Biology, Ecology and Conservation of the Sumatran Elephant *Elephas maximus sumatranus* in Way Kambas National Park, Sumatra. PhD dissertation, Manchester Metropolitan University, Manchester, UK.

Reilly, J., 2002b. Growth in the Sumatran elephant (*Elephas maximus sumatranus*) and age estimation based on dung diameter. Journal of Zoology 258, 205–213.

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

Santiapillai, C., Ramono, W.S., 1993. Reconciling elephant conservation with economic development in Sumatra. Gajah 10, 11–19.

Santiapillai, C., Suprahman, H., 1986. The Ecology of the Elephant (*Elephas maximus* L.) in the Way Kambas Game Reserve, Sumatra. Unpublished report, WWF/IUCN Project 3133, WWF, Indonesia.

Sitompul, A.F., 2004. Human–Elephant Conflict Around Two National Parks in Indonesia, and Conservation Implications. M.S. dissertation, University of Georgia, USA.

Sitompul, A.F., Hedges, S., Tyson, M.J., 2002. Elephant Deaths in Sumatra as a Result of Poaching or Elephant Capture Operations, 1 January 2000 to 1 November 2002. Unpublished report, Wildlife Conservation Society – Indonesia Program, Bogor, Indonesia.

Sody, H.J.V., 1925. Lets over Lampoengschen Olifant. Tectona 18, 1–10.

Sody, H.J.V., 1939. Vijftien jaren olifanten op Sumatra (1924–1938). Tectona 32, 745–771.

Suprayogi, B., Sugardjito, J., Lilley, R.P.H., 2002. Management of Sumatran elephants in Indonesia: Problems and challenges. In: Baker, I., Kashio, M. (Eds.), Giants on Our Hands: Proceedings of the International Workshop on the Domesticated Asian Elephant, Bangkok, Thailand, 5–10 February, 2001. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, pp. 183–194.

Sukumar, R., 1992. The Asian Elephant: Ecology and Management, second ed. Cambridge University Press, Cambridge, UK.

Sunderlin, W.D., 1999. The Effects of Economic Crisis and Political Change on Indonesia's Forest Sector, 1997–99. Center for International Forestry Research, Bogor, Indonesia.

Thomas, L., Laake, J.L., Derry, J.F., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Strindberg, S., Hedley, S.L., Burt, M.L., Marques, F., Pollard, J.H., Fewster, R.M., 1998. DISTANCE 3.5. Research Unit for Wildlife Population Assessment. University of St. Andrews, UK.

Tilson, R., Soemarna, K., Ramono, W., Sukumar, R., Seal, U., Traylor-Holzer, K., Santiapillai, C., 1994. Asian Elephant in Sumatra: Population and Habitat Viability Analysis Report. IUCN/SSC Captive Breeding Specialist Group, Apple Valley, MN, USA.

Tilson, R., Nyhus, P., Franklin, N., Sriyanto, Bastoni, Yunus, M., Sumianto, 2001. Tiger restoration in Asia: Ecological theory vs. sociological reality. In: Maehr, D.S., Noss, R.F., Larkin, J.L. (Eds.), Large Mammal Restoration: Ecological and Sociological Challenges in the 21st Century. Island Press, Washington, USA, pp. 277–291.

Tyson, M.J., Hedges, S., Sitompul, A.F., 2002. Elephant Defecation Rate Study, Way Kambas National Park 2000/2001: Final Report to WWF, WCS, and PHKA, 5 January 2002. Wildlife Conservation Society — Indonesia Program, Bogor, Indonesia.

UNDP/FAO, 1979. Way Kambas Management Plan 1980–1985. Unpublished report, UNDP/FAO National Park Development Project INS/78/061, FAO, Indonesia.

UNEP-WCMC, 2003. UNEP-WCMC Species Database: CITES-Listed Species On the World Wide Web: http://www.cites.org/eng/resources/species.html (accessed on 1 May 2003).

Walsh, P.D., White, L.J.T., 1999. What it will take to monitor forest elephant populations. Conservation Biology 13, 1194–1202.

Wells, M., Guggenheim, S., Khan, A., Wardojo, W., Jepson, P., 1999. Investing in Biodiversity. A Review of Indonesia's Integrated Conservation and Development Projects. The World Bank, East Asia Region, Washington, DC, USA.

White, L.J.T., 1995. Factors affecting the duration of elephant dung-piles in rain forest in the Lopé Reserve, Gabon. African Journal of Ecology 33, 142–150.

Whitten, T., Holmes, D., MacKinnon, K., 2001. Conservation biology: a displacement behaviour for academia? Conservation Biology 15, 1–3.

World Bank, 2001. Indonesia: Environmental and Natural Resource Management in a Time of Transition. The World Bank, Washington, DC, USA.

WWF, 2002. WWF factsheet: Asian elephant (*Elephas maximus*). In: Prepared for the 12th Meeting of the Conference of the Parties to CITES Santiago, 3–15 November 2002. WWF-World Wide Fund for Nature, Godalming, UK.

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.