

CONSERVATION IMPLICATIONS OF HUMAN-ELEPHANT INTERACTIONS IN
TWO NATIONAL PARKS IN SUMATRA

by

ARNOLD FELICIANO SITOMPUL

(Under the Direction of JOHN P. CARROLL)

ABSTRACT

Crop raiding is a major part of human-elephant interactions around Bukit Barisan Selatan National Park (BBSNP) and Way Kambas National Park (WKNP). I quantitatively measured the crop damage and identified the pattern of crop raiding around these two parks. I obtained information on the elephant population size in both parks, and developed a projection model based on differing levels of poaching. Temporal patterns of crop raiding showed that there was no relation between frequency of crop raiding incidents and rainfall pattern. Spatially, crop raiding in BBSNP occurred more frequently at >3 km from the park boundary, whereas in WKNP it occurred <1 km from the park boundary. The elephant population estimate in BBSNP was 498 (373-666, 95% CI), compared to 180 (144-225, 95% CI) in WKNP. Based on population trajectories from my modeling approach, effective protection around these parks is necessary to minimize extinction probability over the next 50 years.

INDEX WORDS: AIC, Asian elephant, Crop damage, Elephant conservation, *Elephas maximus sumatranus*, Habitat destruction, Human elephant conflict, Indonesia, Information theoretic approach, Leslie matrix, Poaching, Population modeling, Sensitivity analysis, Sumatra, Sumatran elephant.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

In addition to habitat destruction and poaching, human-elephant conflicts (HEC) have been identified as a major factor contributing to declining wild elephant populations in Africa and Asia (Sukumar 1989, Thouless 1994, Hoare 1999). Human-elephant conflict has been categorized as the most difficult problem to resolve because it involves ecological, sociological and political components. The conflict between humans and elephants results in negative effects for both people and elephants. Some of the major conflicts include crop depredation, damage to property, such as houses, and severe human injury or even death (Sukumar 1989, Tchamba 1996). Conversely, wild elephants are often shot with rifles, poisoned by local farmers, or captured and kept in captive facilities as a result of these negative interactions with humans (Thouless 1994, Ministry of Forestry 1995, Sitompul *et al.* 2002). As a consequence, elephant populations, especially Asian elephants, continue to decline rapidly in many countries.

In both Africa and Asia, agricultural crop raiding by elephants is the major form of HEC (Sukumar 1989, 1990, Thouless and Sakwa 1995, Hoare 1999). Crops provide the same nutritional rewards for elephants as they do for humans, and elephants are known to raid crops either because natural food abundance in their habitat is not sufficient to support their population size, or because of their optimal foraging strategy (Sukumar and Gadgil 1988, Sukumar 1991, Osborne 1998). On the Indonesian island of Sumatra, Asian elephants are also in conflict with farmers around the few remaining elephant refuges (Santiapillai and Jackson 1990, Nyhus *et al.* 2000).

Farmers and government officials believe HEC to be a significant problem. This has led to pressure on the government to capture large numbers of wild elephants (Santiapillai and Jackson 1990). During the mid 1980s, the Indonesian government responded to the HEC by capturing large numbers of elephants and moving them to Elephant Training Centers (ETC), now known as Elephant Conservation Centers (ECCs; Santiapillai and Jackson, 1990; Lair 1997). By 1993, there were reportedly 217 captive elephants in ECCs in five provinces in Sumatra (Sukumar and Santiapillai, 1993), and by June 1996, there were six ECCs and a total of about 570 elephants had been captured (Lair, 1997). Capturing “problem elephants” and relocating them to zoos or other captive facilities does not necessarily reduce HEC. Furthermore, capturing “problem elephant” has been shown to have a great impact on wild elephant populations.

The aims of this study are to assess the intensity and distribution of HEC around two national parks (Bukit Barisan Selatan National Park - BBSNP and Way Kambas National Park - WKNP) in Sumatra, Indonesia. I propose to: (1) document the level of HEC in two national parks; (2) determine what aspects of HEC resulted in the most severe damage to the crop; (3) determine impact of forest loss to the elephant conservation in Lampung province; (4) determine if there is a correlation between crop raiding frequency and rainfall and harvesting period; (5) determine major crops damaged and compare these to the relative abundance crops around the park boundaries; (6) identify sex and age-structure of the crop raiders; (7) identify pattern in group size of raiding elephant during wet and dry seasons; (8) assess the economic value of the crops lost to elephants; (9) estimate elephant population in BBSNP and WKNP, and (10) develop a populations model to predict future elephant population in three different scenarios. These

objectives are divided into 3 chapters for this thesis. Chapter 2 includes objective 1,2 and objective 3; Chapter 3 includes objective 4, 5, 6, 7 and 8. Chapter 4 relates to objective 9 and objective 10.

LITERATURE REVIEW

Asian Elephant Taxonomy

Taxonomically, the Asian elephant (*Elephas maximus*) is recognized as having 3 subspecies based on the most recent classification, including *E. m. indicus* on the Asian mainland, *E. m. maximus* on Sri Lanka, and *E. m. sumatranus* on the island of Sumatra (Shoshani and Eisenberg, 1982). The designations of these subspecies are based on their morphological characters, such as size and difference in the coloration. Compared to the other subspecies, Sumatran elephant has larger ears, smaller in body size and has an extra pair of ribs (Shoshani and Eisenberg, 1982). Furthermore, mitochondrial DNA (*mt* DNA) sequences studies, strongly suggest that the designation of Sumatran subspecies compared to the other subspecies is quite clear and researchers believes that the Sumatran elephant could be defined as an evolutionarily significant unit (Hartl *et al.* 1996, Fernando *et al.* 2000, Fleischer *et al.* 2001).

Asian Elephant Status

Asian elephant (*Elephas maximus*) populations are continuing to decline due to habitat loss, poaching, and conflict with humans (Santiapillai and Jackson 1990, Sukumar 1989). Throughout 13 range countries, Asian elephant populations were most recently estimated to be about 34,500 — 51,000 in the wild (Kemf and Santiapillai 2000). The species is listed as Endangered in the 2002 IUCN Red List of Threatened Species (IUCN, 2002) and is included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, UNEP-WCMC, 2003). Despite the fact that the wild Asian elephant population is

only 1/10 that of the African elephant, that the African elephant generally receives more conservation attention. However, Asian elephant conservation efforts have been increasing in recent years. For example, in 1997 United States of Fish and Wildlife Service (USFWS) passed the Asian Elephant Conservation Act. This act is designed to provide financial assistance for Asian elephant conservation programs through all range countries (USFWS 2004).

In Indonesia, Asian elephants occur in the island of Sumatra and northeastern part of island of Borneo. The total estimated population in Sumatra is 2,800 – 4,800 elephants (Blouch and Haryanto 1984, Blouch and Simbolon 1985); however the total population estimate in Borneo is unknown. In Sumatra, the Asian elephant is distributed in 44- isolated populations, and during the 1980's, 12 (27 %) of those populations occurred in Lampung Province (Santiapillai and Jackson 1990). As a result, the Lampung province was known to be an important province for elephant conservation. However, human population densities have increased and placed enormous pressures on Lampung's elephant population during this period, which resulted in HEC in most of the elephant habitat.

Human-Elephant Conflicts (HEC)

Crop depredations, damage to the other properties, such as houses, and human injuries or deaths are classified as types of HEC. Among those three types of HEC, crop depredation is known as the greatest and the most frequent problem occurring around elephant habitat. In Asia, HEC had been quite widely studied, especially in India (Sukumar 1989, Sukumar *et al.* 1990). Additional studies have also been conducted in other part of Asia, such as in China (Zhang and Wang 2003). However, in Indonesia, only one HEC study had been done (Nyhus *et al.* 2000), and this study was only based on the rapid assessment interview survey. The accuracy of this

type of technique is debatable. The results are often questionable because there is a strong tendency that interviewed farmers to overestimate the damage (Hoare 1999).

Crop raiding by elephants has received much attention in the last few decades in both Asia and Africa. Studies have shown that there is a great deal of variation on types of crop raiding by elephants and most these tend to be site specific. For example, Sukumar's (1989) study in southern India showed that the types of crops consumed by elephants are commonly analogous with elephant food in the wild. Elephants are known to consume a variety of crops including rice, maize, sorghum, wheat, coconut, bananas, and a variety of vegetables and fruits (Sukumar 2003). In Malaysia, wild elephants often damage oil palm and rubber plantations, and the economic loss of the damage is significant (Stüwe *et al.* 1998). Despite the large variety of crops damaged by elephants, major cultivated crops that are normally raided can be grouped based on three families, Graminea (grasses), Palmae (palms) and Leguminose (legumes) which also is known as a major food of elephant in the wild (Sukumar 1989).

Crop raiding is also known to be seasonal (Parker and Osborn 2001). Some factors considered being responsible for the seasonal pattern of crop raiding are rainfall (Hoare 1999), elephant movement (Tchamba 1996), high nutrient contents in ripe crops (Sukumar 1990), and decline in the food quality in the elephant habitat (Osborn 1998). Furthermore, Sukumar and Gadgli (1988) reported that crop raiding by elephant is partly because of male foraging strategies to obtain extra nutrition from crops to enhance their reproductive success. The relationship between habitat features and crop raiding by elephants has also been identified in Africa (Hoare 1999). The results of this study showed that crop raiding cannot be explained by elephant density, proximity of protected area, area of human settlement and human density, and local rainfall (Hoare 1999). Furthermore, this study demonstrated that crop raiding is unpredictable

because most of the raiding was by bull elephants, so the conflict incidents were strongly associated with behavioral ecology of individual elephants (Hoare 1999). In this case, to understand crop-raiding behavior, we probably need to understand the foraging strategy of bull elephants.

Management of HEC

Several methods have been used in an effort to minimize conflicts between elephants and humans. These include creating physical barriers in elephant habitat (electric fencing and ditches), discouraging elephants from entering agricultural land with chemical deterrents, translocating “problem elephants,” and developing compensation schemes for local people (Sukumar 1989, Thoules 1994, Wamba *et al.* 2001, Osborn 2002). However, these methods are very site specific and sometimes a combination of techniques is necessary to obtain maximum benefit. Before one of the methods above is implemented, it is important to conduct a detailed study of the HEC. Better HEC mitigation strategies can only be achieved if the nature of the conflicts is identified.

Other important aspects that need to be considered to manage the HEC are determining the elephant population size and the habitat availability for the population. Ratnam (1984) classified HEC into three categories based on his study in Malaysia. In the first scenario, HEC occurred around small isolated forest patches. Elephants in this habitat were forced to feed on the agricultural area surround their habitat because of insufficient size of their forest habitat. The second category is where elephants with sufficient habitat raid adjacent agricultural areas and there is a well-defined boundary with the forest. The third is where elephants with sufficient habitat raid adjacent agricultural or settlement areas with no clear boundaries between forests and agricultural areas. To some extent these categories are useful for understanding HEC;

however they do not provide information on the intensity of the crop raiding. To realistically manage HEC, understanding intensity of the conflict is very important. It is important to answer questions relative to temporal patterns, such as regularity of raiding (e.g. occasional versus regular raiding, or even chronic raiding) and how much damage is actually done. Failure to adequately distinguish these characters could result in application of inappropriate management tools for the HEC. In Sumatra, this situation is now occurring and as a result the Indonesian government has been forced to capture numerous wild elephants to mitigate HEC. This has lead to the establishment of Elephant Training Center across Sumatra (Tilson *et al.* 1994). To develop effective mitigation strategies, understanding of the nature of HEC is necessary. Human-elephant conflicts need to be quantified and determined so management recommendation to mitigate the effect can be made.

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CHAPTER 2

**CROP RAIDING BY ELEPHANTS ADJACENT TO TWO NATIONAL PARKS IN
LAMPUNG PROVINCE, SUMATRA, INDONESIA¹**

¹ Sitompul, A.F., S. Hedges, M.J. Tyson, J.P. Carroll, T.G. O' Brien, and J. Santoso. To be submitted to Journal of Applied Ecology

ABSTRACT

I identified the level of human-elephant conflict in two national parks in Lampung Province, Sumatra. Of the 12 areas of Lampung that had elephant populations in the early 1980s, it appears that only three still had resident population in 2002. I used a combination of spatial and interaction data and an Information Theoretic Approach to determine causal factor of crop damage severity. Impact of forest loss in Lampung Province in the last 20-year period also was documented. Given the data from both parks combined, model selection indicated that the best model to predict crop damage severity was distance of the crop raiding, park and the interaction between parks and distance of crop raiding. In WKNP, a combination of number of elephants involved in crop raiding and distance of crop raiding was considered to be the best model. In BBSNP, the best approximation model was explained only by the distance parameter.

INTRODUCTION

Human-elephant conflict is one of the major issues in elephant conservation in Africa and Asia (Sukumar 1989, Hoare 2001). The conflict has become more widespread due to large scale habitat loss. Rapid human population growth and development throughout most of the elephant distribution has caused a dramatic decline in the population (Thouless 1994, Hoare 1999, Zhang and Wang 2003). Extensive forest conversion to agricultural has meant that elephants are now frequently in contact with humans in many areas. As a consequence, humans and elephants compete for space and other resources and, therefore, a conflict between them is unavoidable. The important issue that arises in most of the human-elephant conflict group “discussions” of the Asian and African Elephant Specialist Group in IUCN (World Conservation Union) is weak conservation policies of government in most of elephant range countries to specifically targeting the problem (IUCN 2002). Therefore, human-elephant conflict had never been reduced

significantly. A crucial aspect of human-elephant conflict is that most of the people who have had to face the problems are subsistence farmers who lived next to the elephant habitat. Even if the overall impact of human elephant conflict is low, its effect can be significant to individual farmer (Naughton *et al.* 1998, Chapter 3). As a result, rural communities have negative attitudes towards elephants (de Boer and Baquete 1998). Most biologists believe community-based strategies for elephant conservation are the ones most likely to succeed. However, if the attitudes of the rural communities are not addressed, these strategies will never succeed.

The Sumatran elephant (*Elephas maximus sumatranus*), like other elephant populations in other parts of Asia are endangered because of conflicts with humans around their habitat. Large-scale conversion of forest to oil palm, rubber and *Acacia* plantation – for pulp and paper industry – has reduced elephant and other wildlife habitat dramatically (WWF 2003). In addition, the Transmigration Program implemented by Indonesia in 1980's has been identified as a major factor responsible for reducing wildlife habitat, especially in Sumatra (Fearnside 1997). This is the movement of large numbers of people from Java to Sumatra and other large islands in Indonesia as part of government policy to balance the human distribution between the islands in Indonesia.

In 1980 the total elephant population in Sumatra was believed to be 2,800 — 4,800 elephants distributed in 44 isolated populations (Blouch and Haryanto 1984, Blouch and Simbolon 1985). Today, the population is believed to have declined dramatically compared to 20 years ago and the major factor responsible was human-elephant conflict. A recent field survey, conducted by The Wildlife Conservation Society in Lampung Province in southern Sumatra identified significant elephant populations occurring in two national parks (Hedges *et*

al. in review). However, elephant populations in these parks still faced a risk of extinction due to the poaching, habitat loss, and human-elephant conflicts.

Bukit Barisan Selatan National Park (BBSNP) and Way Kambas National Park (WKNP) are the two national parks in Sumatra that are still considered to have viable elephant populations. The elephant populations in these parks are recognized as significant relative to other populations in Southeast Asia (Hedges *et al.* in review). However, human-elephant conflict in and around these two parks is a serious problem, but the exact issues and mechanisms are relatively unknown. Hoare (1999) suggested that the major causal factors of human-elephant conflicts must be identified before management recommendations can be made. In this study, I documented the level of human-elephant conflicts in two national parks in Lampung Province Sumatra. I used a combination of spatial and interaction data and an Information Theoretic Approach to determine causal factors to the crop damage severity in each of the parks and combined. Finally, I documented the impact of forest loss at the landscape level in Lampung Province and identified the effects on elephant conservation during the last 20-year period.

METHODS

Study Area

The study was conducted in two national parks (Bukit Barisan Selatan National Park-BBSNP and Way Kambas National Park-WKNP) in Lampung Province, Sumatra, Indonesia. BBSNP is known as the third largest park on Sumatra (3568 km²) and is ranked among the top four priority areas for elephant conservation by The World Conservation Union, IUCN (Santiapillai and Jackson 1990). The park is located in southwestern Sumatra (lat 4°31' - 5°57'S, long 103°34' - 104°43' E) and administratively lies in the provinces of Lampung and Bengkulu. Altitude ranges from 0 m to 1893 m above sea level and annual rainfall is 3400 mm – 4200 mm

per year. The vegetation type of BBSNP includes both lowland and mountain tropical rainforest. BBSNP is not just important for wildlife because it is also recognized as a primary watershed for almost all of southwestern Sumatra (Food and Agriculture Organization 1981). However due to a linear narrow shape, this park is vulnerable to disturbance from outside of the park such as illegal logging, poaching and encroachment. Furthermore, lack of buffer zones and the presence of agricultural enclaves in the park, provides many opportunities for human-elephant conflict. The elephant population in the park was estimated to be about 500 animals (Hedges *et al.* in review).

WKNP is located in eastern part of Lampung Province. It is 1,235 km², and the typical vegetation types are tropical lowland and swamp forest. Most of the park was logged in the 1960s and 1970s so most of the park is relatively degraded, however the park had still been categorized as the second highest priority for Sumatran elephant conservation by The World Conservation Union, IUCN (Santiapillai and Jackson 1990). The park is located in Southeast Sumatra (lat 4°62' -5°26' S and long 105°54' -105°90' E). The altitude for the entire park is < 50 m above sea level. Annual rainfall is 2,000 mm – 3,000 mm per year. Total length of the park boundary is estimated about 227 km. About 148 km of the park boundary is bordered by 34 villages, which exist around the park. The elephant population in the park was estimated to be about 200 elephants (Hedges *et al.* in review). The government of Indonesia established the Elephant Training Center (ETC) in the southeastern area of the park in 1980's, to keep all the “problem elephants”. These “problem elephants” were captured as a result of human-elephant conflict in other areas of Lampung Province. The “problem elephants” were then tamed and trained at ETC for tourism purposes. The ETC in WKNP is known as the largest ETC in

Sumatra, and during 2000-2002 of my study period was known to hold about 100 elephants (A. Sitompul, *pers. obs.*).

BBSNP and WKNP are also known to contain other endangered large mammals. Both parks contain significant populations of; Sumatran rhinoceros (*Dicerorhinus sumatrensis*), Malayan tapir (*Tapirus indicus*) and Sumatran tiger (*Panthera tigris sumatraensis*) (O'Brien *et al.* 2003).

Data collections

Crop damage assessment

During June 2000--September 2002 crop damage incident reports from around BBSNP and WKNP were collected. Personnel from an existing local Non-Governmental Organization (NGO), called 'Problem Animal Recorders' (PARs) were trained to assess crop damage by elephant in every village around BBSNP and WKNP. Three teams (two in BBSNP and one in WKNP) visited the villages around the park regularly and measured the damage from any incidents reported by farmers. To maintain consistency in data collection, a sampling protocol for quantifying crop damage was developed. Each crop damage incident was categorized as an independent event. I used a similar definition of an independent event to that described by Naughton-Treves (1998): Independent crop damage events were defined as a single foray occasion, when an elephant crossed the park's boundary, entered adjacent farmland, and damaged crops at a particular time. Crop damage area was measured in square meters (m²) and the number of trees for perennial crops recorded and then translated into area. The details of damage assessment varied depending on the particular crop, but the general procedure was similar. Crops were grouped as full cover crops (rice - assessed on a m² basis), as row- crops

(maize and cassava- assessed on a m^2 basis), and tree crops (bananas and coffee - assessed on a per 100 m^2 basis).

To estimate the areas damaged, I used two considerations. I classified the damage as either a trail of damage or an area of damage. Trail damage occurred when an elephants walked through an area and either did not eat, or only ate along the trail (no widespread meandering patterns). This was most typical in rice fields. If damage was a single elephant trail through a rice field, I measured the trail length and multiplied by 1 meter to obtain a damage area. If damage was extensive, the damage area was mapped and its total area calculated. Date and time of incidents, and herd size and composition were also recorded for each incident. Composition of groups was categorized as mixed groups (elephant groups containing male and female), male groups (groups of elephant containing only male elephants), cow-calf (adult female with infant) groups, and single males. Number of males, females and young were recorded if possible. Number of fields damaged by elephants, type of damage (eaten or trampled), and stage of crop damage were recorded. Coordinate position of crop damage incidents was also determined using Global Positioning System (GPS) Garmin II Plus. Coordinate positions of crop damage were then imported into an Arc View GIS v 3.20 (ESRI[®]) database to determine distance of each crop damage location to the park boundaries. Slope data were calculated by deriving the 90-m Digital Elevation Model (DEM) for both parks. Digital Elevation Model data for BBSNP were collected from The Wildlife Conservation Society and for WKNP, downloaded from United State Geological Survey database (USGS 2002). I then used Grid Pig extension from Arc View to assign the slope value for each incident location. To examine the differences of crop damage incidents between the two parks, I used the non-parametric Mann-Whitney U Test. A Chi-square homogeneity test was applied to examine the intensity of human-elephant conflict at four

different distances (1 km, >1km-2km, >2 km-3 km and > 3km) from the park boundaries in WKNP and BBSNP.

Crop raiding severity

To determine the support model of crop raiding severity with other parameters, I used the Information Theoretic Approach (Burnham and Anderson 2002). I developed multiple linear regression models to determine the severity of crop damage relative to independent variables. I used size of the damaged area as a response variable in the model. Explanatory variables used in the model were distance of crop damage location to the park boundaries, group type of elephant involve in crop raiding (single male coded as: 1 or group coded as:0), elephant abundance estimates in the park adjacent to the crop damage, number of elephants involved in crop raiding, and parks to included combined data from BBSNP (coded as: 0) and WKNP (coded as: 1 Table 2.1). Multiple linear regression models were developed for BBSNP and WKNP where all data from both park are combined. However, I also created multiple linear regression models for each park separately in order to determine differences in the relative importance of predictor variable between the parks.

For the multiple linear regression analysis, I developed 19 combinations of models parameter for all data in both parks combined, and 13 combinations of model parameterization for each BBSNP and WKNP (Table 2.2, 2.4 and 2.6). I kept the same model parameterization in both parks to facilitate the comparison. The best model given each possible combination was determined by using the lowest AIC (Akaike Information Criteria) value and Akaike weight (ω). AIC for each model was computed using the log-likelihood of each model and total number of parameters used in the model (Burnham and Anderson 2002). I also calculated model-averaged parameter estimates, and unconditional standard errors for each parameter (Burnham and

Anderson 2002). Goodness-of-fit test of global model were conducted to identify if there is any over dispersion for count data. Non-over dispersion data was identified by calculating $\hat{c}$ (single variance inflation factor), which is estimated from goodness-of-fit chi square statistic of the global model and its degree of freedom (Burnham and Anderson 2002).

Eleven parameters were combined to develop multiple linear regression models for combined data from both parks. The parameters included in the model were: group (GR), distance (DT), elephant density (ED), elephant (EL), topographic slope (SL) and park (PK). The interaction parameters used were; (EL)*(DT), (ED)*(DT), (PK)*(DT) (SL)*(DT) and (PK)*ED. I included interactions between elephant and elephant density with distance because a higher density of elephant might influence group sizes. Also, elephants in large group sizes might travel more during the raiding for safety reason (Sukumar 1989, McKnight 2000). The interaction between parks with distance was used because number of crop raiding incidents relative to distance from park boundaries showed a different distribution. Slope and distance interaction was used because areas farther away from the park boundaries could have lower slope. Finally, elephant density and park interaction was used because there is a possibility that park conditions could have a specific elephant density. These interaction effects are suspected to be ecologically meaningful in explaining crop raiding severity.

In both BBSNP and WKNP separately, eight parameters were combined to develop linear regression model. Single parameters and the interactions between parameters that I used in the model were; elephant (EL), group (GR), distance (DT), elephant density (ED), topographic slope (SL), (EL)*(DT), (SL)*(DT) and (ED)*(DT). In order to determine the effect of each parameter in the model, I estimated each parameter value with a 95% confidence interval (CI) using PROC REG from SAS (SAS version 8.2).

Impact of forest loss on elephant conservation

Information about changes in forest cover and land use in Lampung province was obtained from interpretation of LANDSAT Thematic Mapper satellite images for 1983-1986 and 2000. Before further analysis was conducted, all images from LANDSAT-TM were geo-referenced to 1:50,000 topographic map from the Topography Division of the Indonesian Army and checked with global positioning systems in the field. The spatial precision of geo-referenced images was approximately 110 m with respect to maps and field measurements, and within 30 m (one pixel) between different images. All the forest area between the 1980's and 2000 were digitized and total forest cover area was calculated and compared using Arc view GIS.

We conducted dung count surveys to estimate elephant population size (see chapter 4) and re-confirmed the existence of the elephant population in remaining forest blocks in Lampung Province. All forest blocks that were known to have elephants in the 1980's from Blouch and Haryanto (1984) were re-surveyed. We used an open interview technique as a preliminary survey to investigate the occurrence of all mammalian pests around villages adjacent to the forest blocks to avoid biased answers from villagers. After the interview surveys were completed and the existence of human-elephant conflict was known, I then conducted dung count survey (Barnes and Jensen 1987, Barnes 1993) to estimate the elephant population in the area where human elephant conflict was reported.

RESULTS

Crop damage assessment

During the 28 months of the study (June 2000 – September 2002), 340 crop damage incidents around BBSNP with a total area of damage of 12,952 m² were recorded. A total of 377 crop damage incidents were recorded around WKNP, and the total area damaged was 219,517 m². Most (200) of the BBSNP incidents occurred between March 2002 and June 2002 due to two persistent groups of raiding elephants. In BBSNP, elephants damaged at least 20 houses during the same period, 2 people were killed, and 1 person was permanently injured. In WKNP during the same period, 1 house was damaged and elephants injured 1 person. The number of incidents per month in BBSNP was greater than in WKNP (Fig 2.1, Mann-Whitney U Test, $Z = -2.32$, $n = 28$, $P < 0.05$). Crop damage incidents around WKNP were more equitably spread throughout the year and occurred equally in the northern and southern parts of the park. In BBSNP, crop damage incidents were more concentrated along the eastern and western boundaries of the center part of the park. Incidents in BBSNP were more clustered than in WKNP (Fig. 2.2 & 2.3).

About 38.5% of the total number of incidents in BBSNP occurred at distances of more than 3 km from the park's boundaries, whereas the spatial distribution of incidents around WKNP were much closer to the boundary with 60% of the incidents occurring <1 km from the park's boundaries (Fig 2.4). There was a difference between expected and observed frequencies of crop raiding incidents among the 4 distance classes for the pooled data ($\chi^2 = 49.17$, 3 df, $P < 0.01$). However, in WKNP the severity of crop raiding among the four-distance classes was

different ($\chi^2 = 44.72$, 3 df, $P < 0.01$). In BBSNP no difference in the severity of crop raiding in four different distance classes was found ($\chi^2 = 4.889$, 3 df, $P < 0.180$).

Relationship of crop raiding severity with other parameters

Given the data from both parks combined, the best approximating model showed that crop damage severity was linearly related to distance of the crop raiding, park and the interaction between parks and distance of crop raiding. However, the second model containing all those factors and elephant density had a substantial level of empirical support ($\Delta AIC < 2$, Table 2.2, Burnham and Anderson 2002). Model average effect estimates for data from both parks combined showed that the variables of number of elephant involved in the crop raiding, park, and interaction between park and elephant density in the park adjacent to the crop raiding location had a positive effect on the severity of crop damage (Table 2.3). The $\hat{\beta}_j$ estimate for number of elephants involved in a crop raiding incidents is 27.84 (9.36 SE), park is 858.84 (162.01 SE) and the interaction between elephant density and park is 2044.98 (371.99 SE). The large negative effect of severity of crop damage is found in the group and slope parameter. The $\hat{\beta}_j$ estimate for group parameter is -614.12 (119.64 SE) and slope is -25.49 (8.78 SE). This result indicated that single male elephant caused less damage than groups of elephants and high slope areas tended to have less damage compared to lower slope areas.

In BBSNP, the best approximating model representing the crop damage severity around the park was explained only by the distance parameter ($\omega = 0.25$). However, several other parameterization involving the combination of distance with individual parameter of group, slope, number of elephant involves in the raiding and elephant density in the park adjacent to the crop raiding incidents had substantial empirical support to the model ($\Delta AIC < 2$, Table 2.4,

Burnham and Anderson 2002). Other combinations of model parameters (Table 2.4) had at least a reasonable level of support ($\Delta AIC < 7$, Burnham and Anderson 2002). Model average estimate effects of parameter for crop raiding around BBSNP showed that only distance had positive effect on the severity of crop damage. However, the effects were relatively small ($\hat{\beta}_j = 0.07, 0.03 \text{ SE}$). Other parameters (group type, topographical slope, elephant density in the park adjacent to the crop raiding location, number of elephant involve in crop raiding) and the interaction of between parameters such as elephant density with distance tended to have no effect on the crop damage severity (Table 2.5).

When data from each park were treated separately, the best model and estimates of the model average effect show an interesting result. For crop damage in WKNP, the best approximating model given the data contains number of elephant involve in crop raiding and distance of crop raiding ($\omega = 0.91$). However, the models with group and distance parameters, number of elephant involve during crop raiding, the number of elephant involve during raiding and topographical slope parameter had considerably less empirical support ($4 < \Delta AIC < 10$, Table 2.6, Burnham and Anderson 2002). Model average of parameter estimate for crop raiding in WKNP indicated that number of elephants involved in the raiding incidents, elephant density in the park adjacent to the crop raiding location and group type had large effects on the severity of crop damage (Table 2.7). Parameter estimate for number of elephant involve in crop raiding was 77.18 (14.60 SE), elephant density was 1660.28 (710.53 SE). Negative effects of other parameter to the severity of crop damage were found in-group parameters with $\hat{\beta}_j$ estimates of -614.28 (119.60 SE), distance parameters with $\hat{\beta}_j$ estimates of -0.21 (0.06 SE) and the

interaction between slope and distance parameter ($\hat{\beta}_j = -0.27, 0.07 \text{ SE}$). This result indicates, number of elephant involves in the crop raiding, non-single male group of elephant and elephant density in the park adjacent to the crop raiding location was important parameter than slope and interaction between slope a distance parameter.

Impact of forest loss to the elephant conservation in Lampung

The interpretation of the satellite imagery for the forested area in the mid-1980s showed that forest cover in these areas declined from 7,814 km² to 4,284 km² in 2000 (Fig. 2.5). About seven forests blocks had been completely, or almost completely, deforested and converted to agriculture, plantations, and settlements. Average of forest loss was about 246 km² per year. Most of the forest conversions occurred on lowland forest areas in the northern part of the province. The lowest levels of forest degradation occurred within the national park areas. Status of the type of forest area seems to be the important factor in keeping the forest intact in the future, because most of the forest area that had been converted to another type of land use in the last 15 years did not have strong protection status. Of the 12 areas of Lampung that had elephant populations in the early 1980s, it appears that only 3 still had resident population in 2002. These were BBSNP, WKNP and the Gunung Rindingan-Way Paya complex (Fig 2.6).

DISCUSSION

Crop damage assessment

Crop raiding by elephants was identified as a major part of human elephant conflict both in BBSNP and WKNP. However the pattern of the crop damage among parks was quite different. Human-elephant conflict around BBSNP to be clustered and more seasonal compared to the WKNP. Conflict locations in BBSNP mainly occurred in the Sekincau area and western

area of central part of the park (Fig 2.2). The other interesting pattern of crop raiding incidents in both parks is that the total number of incidents during the study period was relatively equal, even though BBSNP had far longer boundaries compared to WKNP. Sukumar (1990) believed that longer-range park boundaries would increase the probability of crop raiding by elephants. Result of my study did not support that argument. WKNP boundaries that are exposed to the settlement area is far shorter (± 148 km) than BBSNP (± 700 km), but frequency of crop raiding incidents in WKNP was higher than BBSNP. There are several reasons for why this could have occurred. First, landscape topography between the two parks is relatively different. BBSNP has more steep terrain compared to WKNP. Relatively flat topographical area in WKNP might facilitate elephant movements from forested area to agricultural area. Furthermore, about 25.5 km of the area around the park has no boundaries between elephant habitat and agricultural area. Easy access to the agricultural area, relatively close and poorly defended crop field probably important factor that might derive crop-raiding incidents in WKNP. Second, disturbances to the elephant habitat in WKNP are relatively higher compared to BBSNP. Intense illegal logging in the northern part of the park and active encroachment in the northern central part of the park are believed to be responsible for reducing elephant habitat quality in the park. In fact, current farmers around the WKNP have claimed about 10% of the park and converted the forest area to agriculture in last 5 years (Bintoro, Head of WKNP, pers comm. 2002). Similar results also were found in Ghana, where farming and logging within the park could increase the number of elephants close to edge of the park (Barnes *et al.* 1995).

If we overlay the elephant density map with conflict incident locations, it shows that human-elephant conflicts occurred along parks boundaries adjacent to both high and low elephant density in BBSNP and WKNP (Fig 2.2 and 2.3). The results of the study seem to show

that there is no obvious relationship between elephant density within any given sector of the park and raiding frequency adjacent to that sector. Similar results also found by Hoare (1999), where human-elephant conflicts in African savannas did not depend on elephant population density. Human-elephant conflicts in both parks are most likely expressed by a combination of several factors. First, we suspect that human activities around the park boundaries play an important role in determining the frequency of crop raiding. For example, the southern part of the park in the peninsula area (Tampang-Belimbing) is known to have a high elephant density, but this area has relatively low human disturbance (Kinnaird *et al.* 2003), and therefore, crop raiding hardly ever occurred on that area. Hoare (1999) argued that human settlement in a matrix of elephant habitat is one of the major factors that could drive human elephant conflicts in Africa. This situation is probably also happening in BBSNP and WKNP.

Another factor that is also important in determining human-elephant conflicts is the level of habitat disturbance in the area. Based on studies by Kinnaird *et al.* (2003), in BBSNP the average deforestation rate could reach 2.0% per year. The slowest rates occurred from 1989 to 1994 (1.58% per year) and the highest rate occurred from 1994 to 1997 is 3.1% per year (Kinnaird *et al.* 2003). Furthermore, they found that core forest area was reduced to 34% in 1985 and the distribution of forest cover was highly fragmented. The fragmentation increased in 1999 and core forest area declined down to only 22% of the remaining forest area (Kinnaird *et al.* 2003). Our studies indicated that the high deforestation area identified by Kinnaird *et al.* (2003) is highly correspondent to the area with the high intensity of human elephant conflict (Fig 2.7).

Data from this study showed that in WKNP, “frontline farms” (farming area < 1 km from park boundaries) have suffered more compared to the area farther away from park boundaries.

However this pattern did not occur in BBSNP. This difference might have occurred because in WKNP park boundaries are well defined and there is a clear difference between the areas inside and outside the park. In these situations, when elephants raid crops, the farmers always respond immediately by driving them back before they have moved too far from the park. In BBSNP, the park's boundaries are not so well defined. In some parts of BBSNP, especially in the Sekincau area (the area where most conflict occurred during this study), there is no clear difference in vegetation conditions between areas inside and outside the park. Most of the areas inside the park in the Sekincau regions are degraded and look very similar to the areas outside of the park. In this situation, when conflict occurs, farmers do not really know how far they need to drive the elephants back into the park and sometimes do not even attempt to drive them back. For this reason, elephants can travel a long way from the park boundaries in this region. The other possibility is in WKNP, the elephants easily know when they are outside the park because the landscape is so different between the inside and outside of the park. Inside the park the vegetation type is forest and scrub (natural vegetation), whereas outside the park it is agriculture and settlements. The elephants may feel less secure outside and so may be too frightened to move very far from the park boundaries. In BBSNP, because the edges are not so clear, the elephants probably cannot tell so easily when they are in the park or outside the park. Therefore, they can move farther from the park and still feel fairly safe.

Crop raiding severity

Model parameterization when data from both parks were combined together showed that crop damage severity was highly affected by a combination of several parameters ($\Delta \text{AIC} < 2$, Table 2.2.). In this case we argue that crop damage severity by elephants in general is more likely to be determined by a combination of several factors. A park's parameter is known to

have a strong effect on the crop damage severity, which implies that crop damage severity by elephant is considered to be site specific. Interaction between park and elephant density also has a strong effect on the crop damage severity. Other parameters that can have a greater effect on the crop damage severity is group type and slope, however this effect was found to be negative. Negative effects on group type in this study means that crop raiding by non-single male groups (mixed group, male group and cow-calf group) tend to cause more severe damage than single male. Other negative effects in the model also occurred for the slope parameter, which means that crop fields that occur at higher slopes had less damage than the crop fields at lower slopes. The parameter estimates for data set from both parks, also indicated that numbers of elephants involved in raiding had a great effect on the severity of crop damage. Large numbers of elephants involved in the raiding incidents more likely caused more intensive damage than single male raiders.

The best-supported model for crop damage severity in BBSNP is more likely to be determined by distance of crop field to the park boundaries. Parameter estimates in BBSNP indicated high severity of crop damage occurred when distance of crop field increased from the park boundary. In contrast, in WKNP, the severity of crop damage decreased when distance of crop field increased from the park boundary. Difference in the distance relative to the severity of crop damage in BBSNP and WKNP was probably affected by the different spatial planting regime between two parks. Farmers in BBSNP planted palatable crops (such as; rice and vegetables) relatively farther away from the park boundaries.

In WKNP elephant density and number of elephants involved in single incidents seemed to have a greater effect on the crop damage severity but not so much in BBSNP. This result showed, a consistency in the model parameterizations even if data from both parks were

combined. The model parameterization showed that, in both parks, bull elephant raiders were not considered as the most responsible factor causing more damage compared to the group elephants. There are four major factors cause this phenomenon in WKNP. First is “more guts-more food”, crop-raiding elephants that travel in large groups tend to damage more crops because there are more individuals that have to eat. Second, elephants that raid crops in-groups probably felt more secure raiding crops compared to single elephants. Similar results were also found in India, where bull elephants tend to form larger groups to increase safety during raiding (Sukumar 1989). Furthermore, groups of crop raiding elephants are relatively more difficult to drive back into the forest than single individuals. As a result, they stay longer in the crop field and cause more damage. In fact, mean damage area caused by single bulls was much less than by group of elephant (Chapter 3). Third, there is a possibility that crop-raiding elephants who travel in a group tend to travel farther away from the park boundaries compared to the single bull. Similar results also were found in Tsavo East National Park, Kenya (McKnight 2000). The study suggests that young elephants (both sexes) are more likely to congregate with adult female elephants to learn about resources and for security reasons (McKnight 2000). Fourth, there is possibility that the configuration of elephant population WKNP is dominated by groups of elephants rather than single males. Results from study by Reilly (2002) support this argument. Age estimation using dung diameters in WKNP concluded that the elephant population in WKNP dominated by young individuals and sub-adults (age 5-15 years, Reilly 2002). Furthermore, data from ECC in WKNP also show that during 1984 to 1997, most elephants caught from the WKNP and moved to the training center were young males (90% of elephants were less than 10 years old, $n=20$). From these data we could conclude that raiding by groups of elephants was probably also the main type of crop raiding in the past around WKNP.

Impact of forest loss to the elephant conservation in Lampung

Habitat loss is the most likely cause of the decline of Lampung's elephants over the past two decades. The loss of 9 out of 12 elephant populations between 1984 and 2002 can presumably be attributed to habitat loss as the area under plantation and agriculture expanded in the 1980s. This major habitat loss was mainly because of the Indonesian government policies of the Transmigration program. Between 1980 and 1995, the local government of Lampung Province implemented the transmigration program in collaboration with the Ministry of Forestry and resettled to northern Lampung 70,000 families that they had classified as forest squatters (Levang *et al.* 1999). As the number of people in Lampung increased, the area under forest cover decreased. In the early 1960's, forest cover was still about 44%, but by 1985 it had decreased to under 20% (Santiapillai and Suprahman 1986, World Bank 2001). Forest degradation increases during that period because numerous logging licenses were issued to companies to harvest timber on a supposedly sustainable basis. Unfortunately, the companies were inadequately supervised and generally all saleable timber was cut with little regard for the damage caused to the residual stand. Largely as a result of these cumulative problems, forest cover in Lampung declined from approximately 19.1% in 1985 to approximately 10.8% in 1997, which is the second highest rate of any Sumatran province (World Bank 2001). As the result of habitat loss, human-elephant conflicts are increasing linearly. In the last 20 years, Lampung Province has been characterized as a province with continuous human-elephant conflict (Santiapillai and Jackson 1990). In response to human-elephant conflict, the Indonesian government captured large number of elephants and moved them to elephant training centers (ETCs). In 1996, there were six ETCs and a total of about 570 elephants had been captured (Santiapillai and Jackson 1990, Lair 1997).

MANAGEMENT IMPLICATIONS

Crop raiding by elephant in BBSNP and WKNP showed a different pattern during the study periods. Even though the total number of incidents was quite similar, but the severity of crop damage and the spatial and temporal pattern of the crop raiding in both parks are relatively different. Therefore, management strategies to mitigate the crop raiding by elephants in each park are probably going to be different. In WKNP, the crop-raiding mitigation scheme should be focused along the park boundary. Planting alternative crop in certain buffer zones along the park boundary would probably be the better approach to mitigate the crop raiding around the park. Palatable crops such as rice, maize and cassava should be planted farther away from park boundary. In combination with planting alternative crops, creating “crop protection unit” (CPU) to force the elephants back (working together with farmers) into the forest should be considered as an alternative approach to mitigating crop raiding by elephants. The most vulnerable area for conflicts was identified as the area where there was no natural boundary between the park and agricultural area. In southwestern part of the park, 25.5 km of park border had no boundaries. This area should be prioritized for crop raiding mitigation scheme. Based on this study, this area received 54.2% ($n = 377$) of the damage incidents during my study period. It may be most effective to build a watchtower is best to build along this park boundary to assist farmers to identify and locate the elephants before they enter the crop field. It would be easier to prevent the elephant from entering the crop field than driving them back to forest.

Elephant density might increase number of crop raider elephant around the park if the intensity of habitat disturbance is consider to be high due to the acute illegal logging and encroachment activity in the park. This situation probably forces elephants to come out of the park and raid crop-fields for alternative food sources. I found evidence that elephant density and

number of elephants involved in the raiding incidents have caused more severe damage to crop fields. Therefore, illegal logging and encroachment should be stopped in the park because I believe that will reduce the quality of the habitat.

Based on this study, in BBSNP, the central part of the park is identified as concentration area for the most crop raiding incidents. From this study, we found evidence that around BBSNP, damage was relatively higher in the area farther away from the park boundary. Therefore, I believe that conflict management should focus on decreasing the possibility of elephant traveling farther away from the park boundary. One of the alternative techniques for preventing elephant movement out of the park is by improving the habitat quality and creating buffer areas to increase the amount of habitat for them.

Capturing “problem elephants” to mitigate crop raiding in both park may not be effective, because it is not targeting the cause of crop raiding. In contrary, this technique may be detrimental to the elephant population in the wild. The results of this study have shown that crop raiding by elephant is very site specific, therefore the management to mitigate the conflict should be based on the characteristic of the conflict. It is very likely that elephant population structure and combination with specific environmental factors at each site play important role to predict the crop-raiding pattern.

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Table 2.1. Description of parameters used to describe characteristics of crop raiding by Asian elephants in Lampung Province, Sumatra, Indonesia.

Parameter	Description
Group (GR)	Group composition of elephants involve in crop damage, (Coded as single male=1 and other form of groups; herds, all male and female with infant =0)
Elephant Density (ED)	Elephant density in the park adjacent to the incident locations
Elephant (EL)	Total number of elephants involved in a crop raiding
Slope (SL)	Topographic slope of the incidents area
Distance (DT)	Distance between each crop raiding incident and the nearest park boundary
Park (PK)	The location of incidents (Coded as BBSNP=0 and WKNP=1)

Table 2.2. Multiple regression models for the crop damage severity by Asian elephants for BBSNP and WKNP data combined (n= 356). Models are ranked from the highest to lowest base on Akaike's Information Criterion (AIC), delta (ΔAIC), Akaike weight (ω_i) and number of parameters (K).

	Model	AIC	ΔAIC	ω_i	K
Crop damage severity	Distance+Park+Park*Distance	4767.972	0	0.466028	4
	Distance+ED+Park+Park*Distance	4768.268	0.296	0.401917	5
	Group+Distance	4771.229	3.257	0.091446	3
	Park*ED	4772.876	4.904	0.040135	2
	Group	4782.296	14.324	0.000361	2
	Distance+Elephant	4786.468	18.496	4.49E-05	3
	Elephant+Slope	4786.565	18.593	4.28E-05	3
	Park	4789.636	21.664	9.21E-06	2
	Slope+Distance	4790.171	22.199	7.05E-06	3
	Distance+ED+Park	4790.747	22.775	5.28E-06	4
	Distance	4793.315	25.343	1.46E-06	2
	Elephant	4794.624	26.652	7.6E-07	2
	Slope	4794.962	26.99	6.42E-07	2
	Distance+ED	4795.239	27.267	5.59E-07	3
	Slope*Distance	4796.291	28.319	3.3E-07	2
	Park*Distance	4799.016	31.044	8.46E-08	2
	ED*Distance	4799.38	31.408	7.05E-08	2
	Elephant Density (ED)	4801.121	33.149	2.95E-08	2
	Elephant*Distance	4801.133	33.161	2.93E-08	2

Table. 2.3. Multiple linear regression parameter estimates for crop damage severity by Asian elephants in BBSNP and WKNP, Lampung Province, Sumatra, Indonesia during June 2000 – September 2002.

		95% CI			
Parameter ^a		$\hat{\beta}_j$	SE	Lower	Upper
Crop damage severity	Intercept	48.86	279.28	-498.53	596.25
	Elephant	27.84	9.36	9.50	46.18
	Group	-614.12	119.64	-848.61	-379.62
	Distance	0.06	0.08	-0.08	0.21
	Elephant density	398.36	701.44	-976.45	1173.18
	Park	858.84	162.01	541.29	1176.38
	Slope	-25.49	8.78	-42.69	-16.71
	Park*Distance	-0.17	0.21	-0.57	0.23
	Park*ED	2044.98	371.99	1313.40	2776.57
	Slope*Distance	-0.01	0.004	-0.02	-0.002

^aParameter descriptions. Elephant – number of elephants in raiding group, Group – sex and age composition of raiding elephants, Distance – distance from crop raiding incident and nearest park boundary, Elephant density – Density of elephants in portion of park adjacent to the crop raiding incident, Slope – relative slope of area where crop raiding incident occurred, and Park – BBSNP or WKNP.

Table 2.4. Multiple regression models for the crop damage severity for BBSNP (n= 108). Models are ranked from the highest to lowest base on Akaike's Information Criterion (*AIC*), delta (ΔAIC), Akaike weight (ω_i). *AIC* is based on $-2 \times \log$ likelihood and the number of parameters in the model (*K*).

Model		<i>AIC</i>	ΔAIC	ω_i	<i>K</i>
Crop damage severity	Distance	1366.73	0	0.25	2
	Elephant+Distance	1367.54	0.81	0.17	3
	Slope+Distance	1368.12	1.38	0.13	3
	Group+Distance	1368.52	1.78	0.10	3
	ED+Distance	1368.72	1.99	0.09	3
	Group	1370.36	3.63	0.04	2
	Elephant Density (ED)	1370.47	3.74	0.04	2
	Slope	1370.48	3.75	0.04	2
	Elephant	1370.71	3.98	0.03	2
	ED*Distance	1370.79	4.06	0.03	2
	Elephant*Distance	1371.08	4.35	0.03	2
	Elephant+Slope	1371.46	4.73	0.02	3
	Distance*Slope	1371.61	4.87	0.02	3

Table. 2.5. Multiple linear regression parameter estimates for crop damage severity in BBSNP in Lampung province.

				95% C.I.	
Parameter ^a		$\hat{\beta}_j$	SE	Lower	Upper
Crop damage severity	Intercept	114.40	127.77	-136.03	364.83
	Elephant	-10.06	9.67	-29.00	8.88
	Group	-104.13	168.25	-433.91	225.65
	Distance	0.07	0.03	0.004	0.127
	Elephant Density	-151.89	246.35	-634.73	330.95
	Slope	-7.07	6.80	-20.39	6.25

^aParameter descriptions. Elephant – number of elephants in raiding group, Group – sex and age composition of raiding elephants, Distance – distance from crop raiding incident and nearest park boundary, Elephant density – Density of elephants in portion of park adjacent to the crop raiding incident, and Slope – relative slope of area where crop raiding incident occurred.

Table 2.6. Multiple regression models for the crop damage severity for WKNP (n= 248). Models are ranked from the best to the worst based on Akaike's Information Criterion (AIC), delta (ΔAIC), Akaike weight (ω_i). AIC is based on $-2 \times \log$ likelihood and the number of parameters in the model (K).

	Model	AIC	ΔAIC	ω_i	K
Crop damage severity	Elephant+Distance	3346.43	0	0.911546	3
	Group+Distance	3351.82	5.39	0.061476	3
	Elephant	3354.53	8.10	0.015897	2
	Elephant+Slope	3355.27	8.84	0.01097	3
	Group	3365.03	18.60	8.33E-05	2
	ED+distance	3367.85	21.42	2.04E-05	3
	Slope+Distance	3371.21	24.79	3.78E-06	3
	Distance	3371.35	24.92	3.54E-06	2
	Elephant density (ED)	3375.80	29.37	3.82E-07	2
	Distance*Slope	3376.34	29.91	2.91E-07	2
	Slope	3386.50	40.07	1.81E-09	2
	Elephant*Distance	3387.28	40.85	1.23E-09	2
	ED*Distance	3388.01	41.58	8.54E-10	2

Table. 2.7. Multiple linear regression parameter estimates for crop damage severity in WKNP in Lampung province.

		95% CI			
Parameter ^a		$\hat{\beta}_j$	SE	Lower	Upper
Crop damage severity	Intercept	530.36	169.00	199.13	861.59
	Elephant	77.18	14.60	48.56	105.78
	Group	-614.28	119.60	-848.70	-379.86
	Distance	-0.21	0.06	-0.34	-0.08
	Elephant density	1660.28	710.53	267.63	3052.93
	Slope	-163.844	146.78	-451.52	123.84
	Slope*Distance	-0.27	0.07	-0.41	-0.13

^aParameter descriptions. Elephant – number of elephants in raiding group, Group – sex and age composition of raiding elephants, Distance – distance from crop raiding incident and nearest park boundary, Elephant density – Density of elephants in portion of park adjacent to the crop raiding incident, Slope – relative slope of area where crop raiding incident occurred.

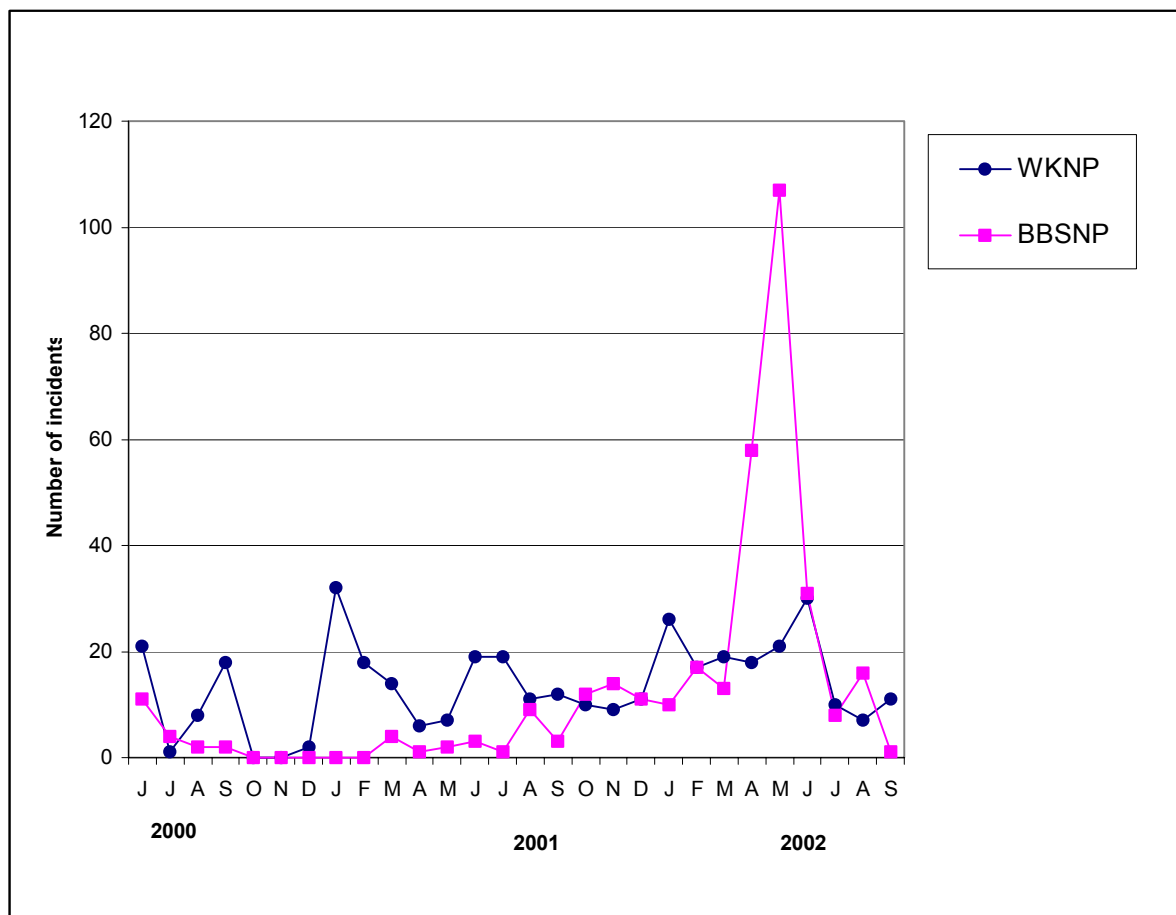


Figure 2.1. Total number of crop raiding incidents involving elephants in areas around WKNP and BBSNP, Lampung Province, Sumatra, Indonesia during June 2000- September 2002.

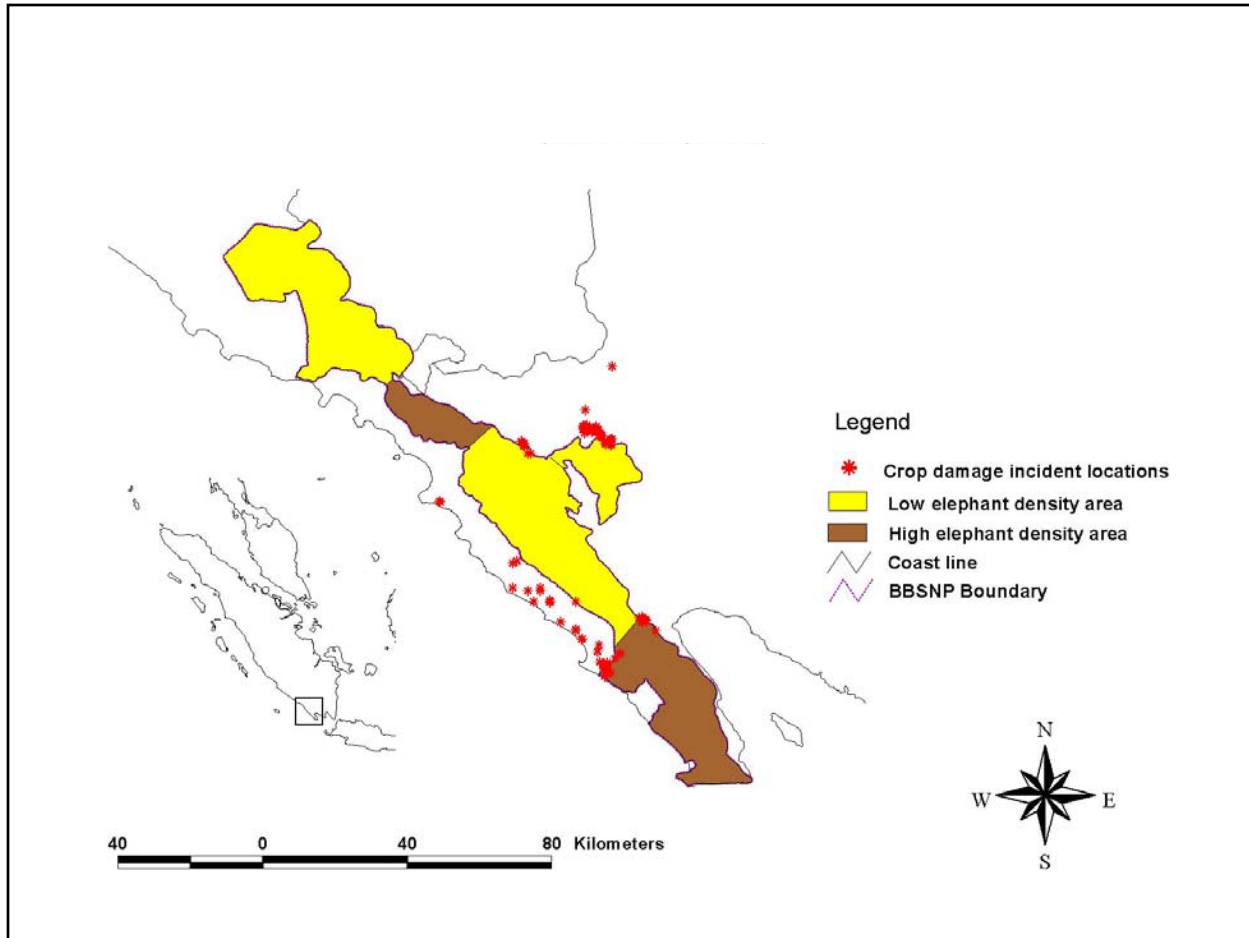


Figure 2.2. Distribution of crop raiding incidents around Bukit Barisan Selatan National Park, Lampung Province, Sumatra, Indonesia during June 2000 - September 2002.

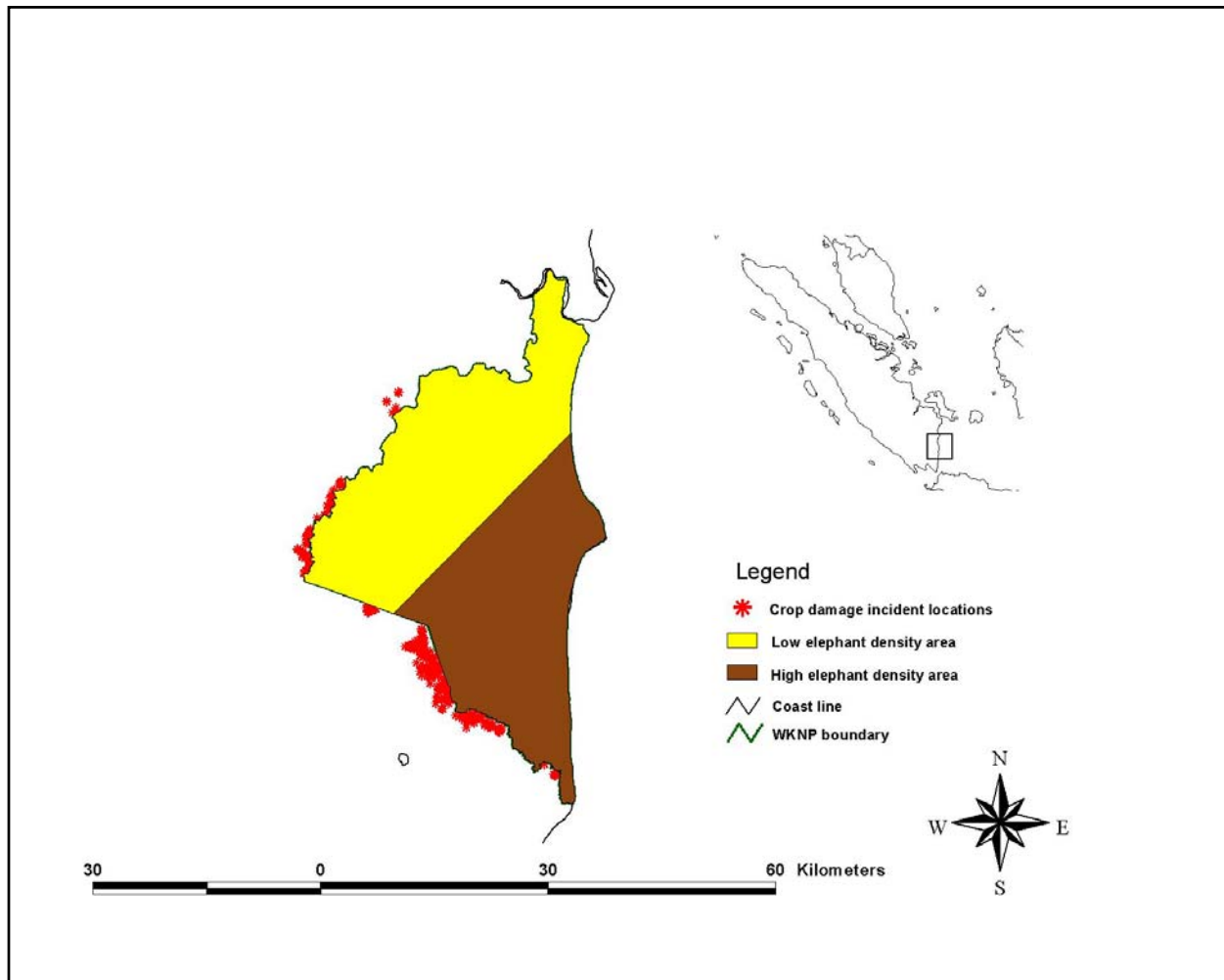


Figure 2.3. Distribution of crop raiding incidents around Way Kambas National Park, Lampung Province, Sumatra, Indonesia during June 2000 - September 2002.

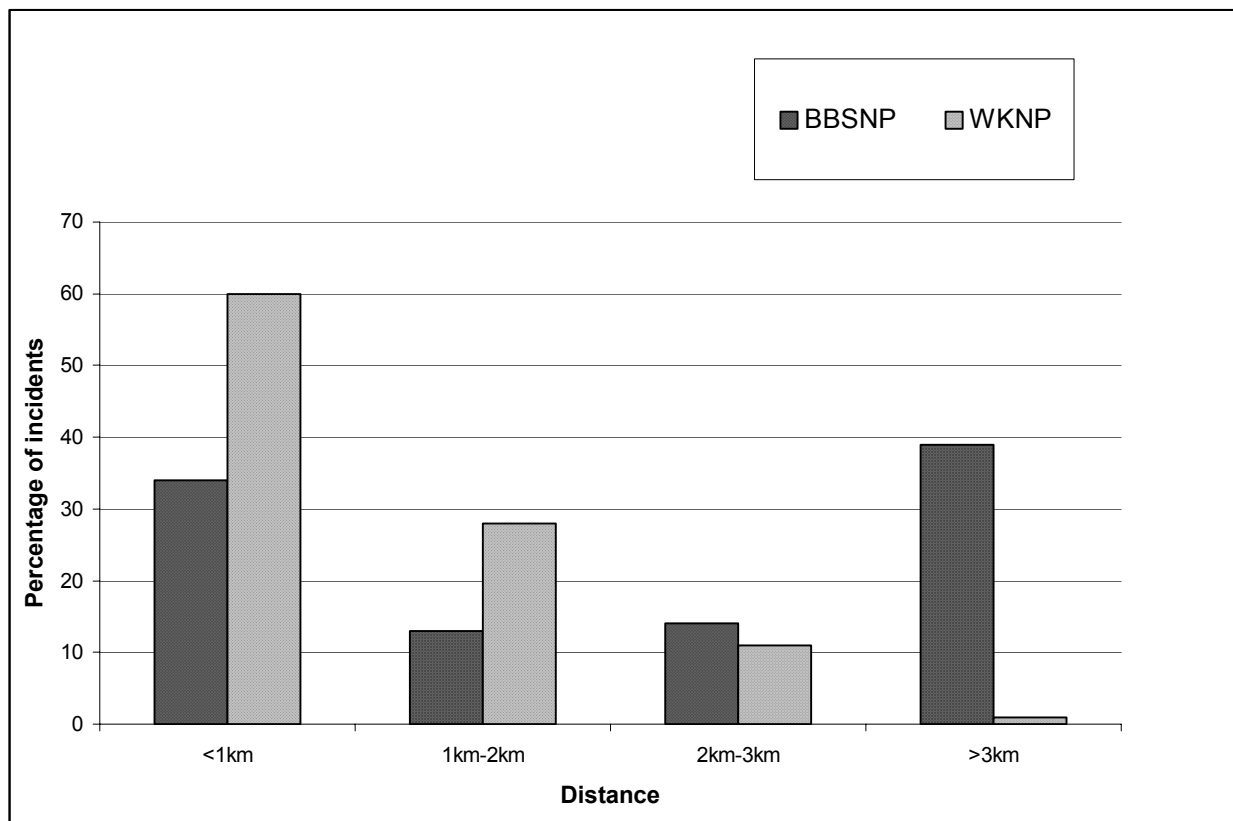


Figure 2.4. Distribution of crop raiding incidents by elephants relative to the distance from park boundary in BBSNP and WKNP, Lampung Province, Sumatra, Indonesia during June 2000 - September 2002.

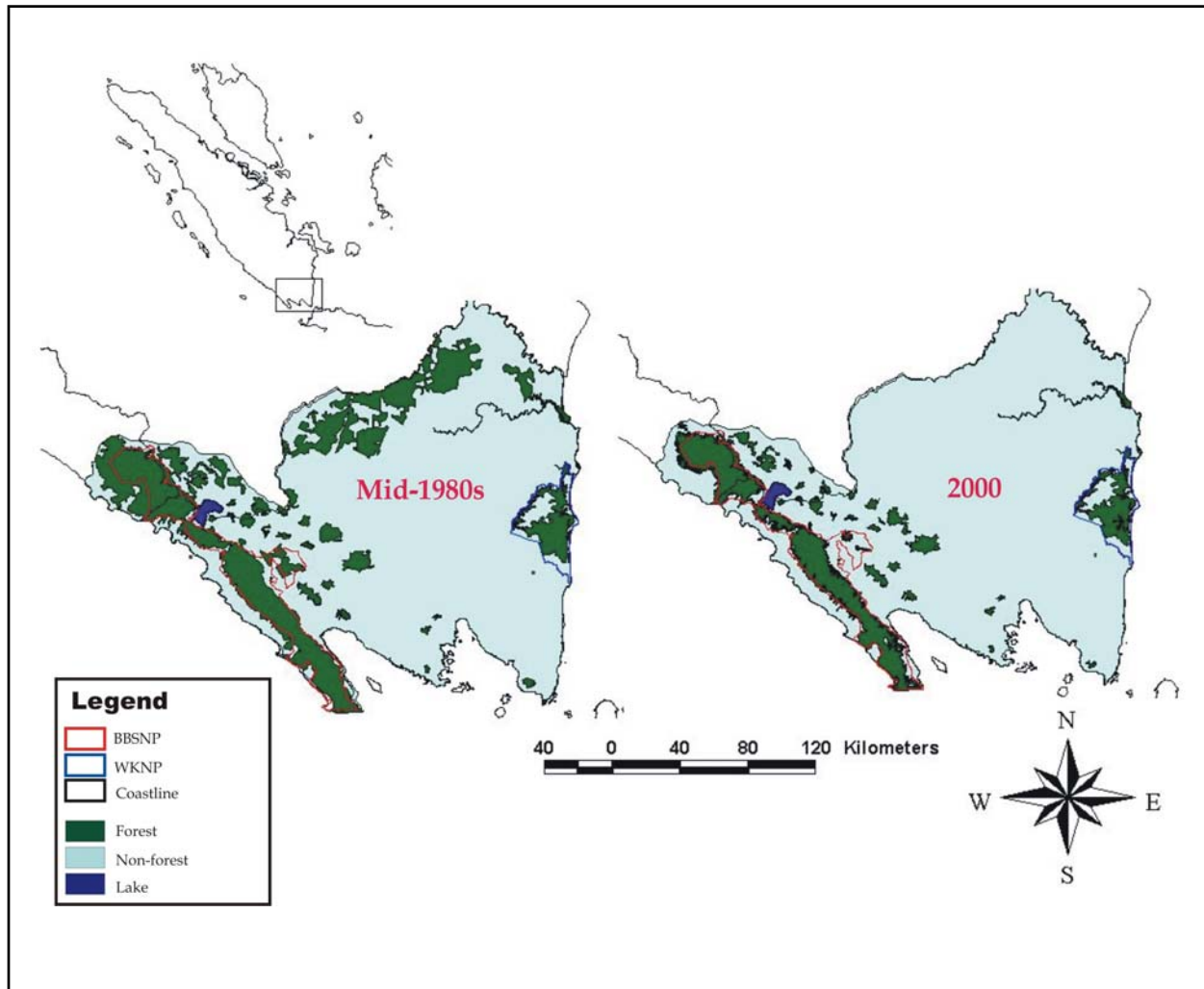


Figure 2.5. Changes of forest cover during mid-1980s to 2000 in Lampung Province, Sumatra.

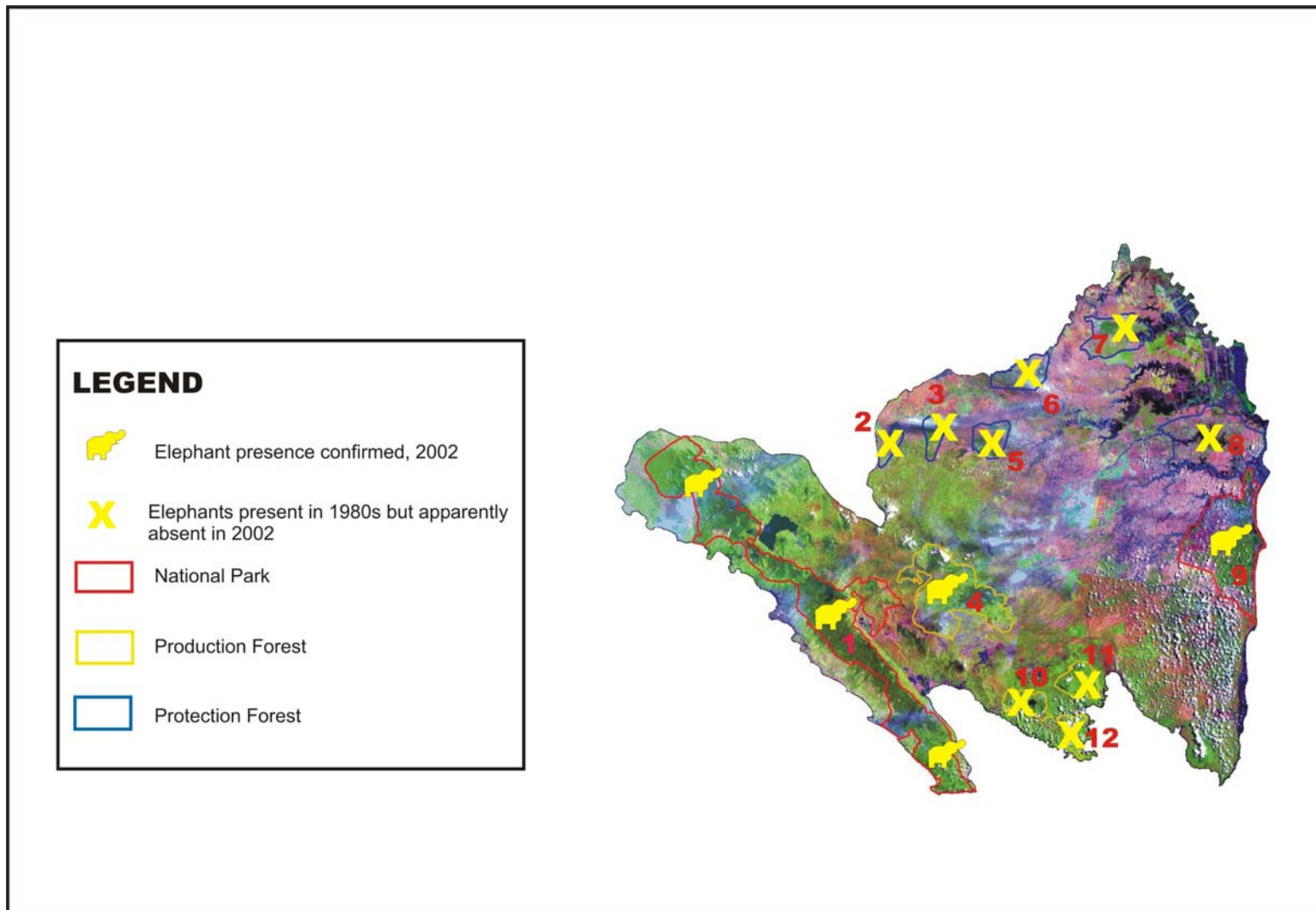


Figure 2.6. Change in Asian elephant population distribution in Lampung Province, Sumatra, Indonesia during the mid-1980s to 2000. Bukit Barisan Selatan National is number 1 and Way Kambas National Park is number 9.

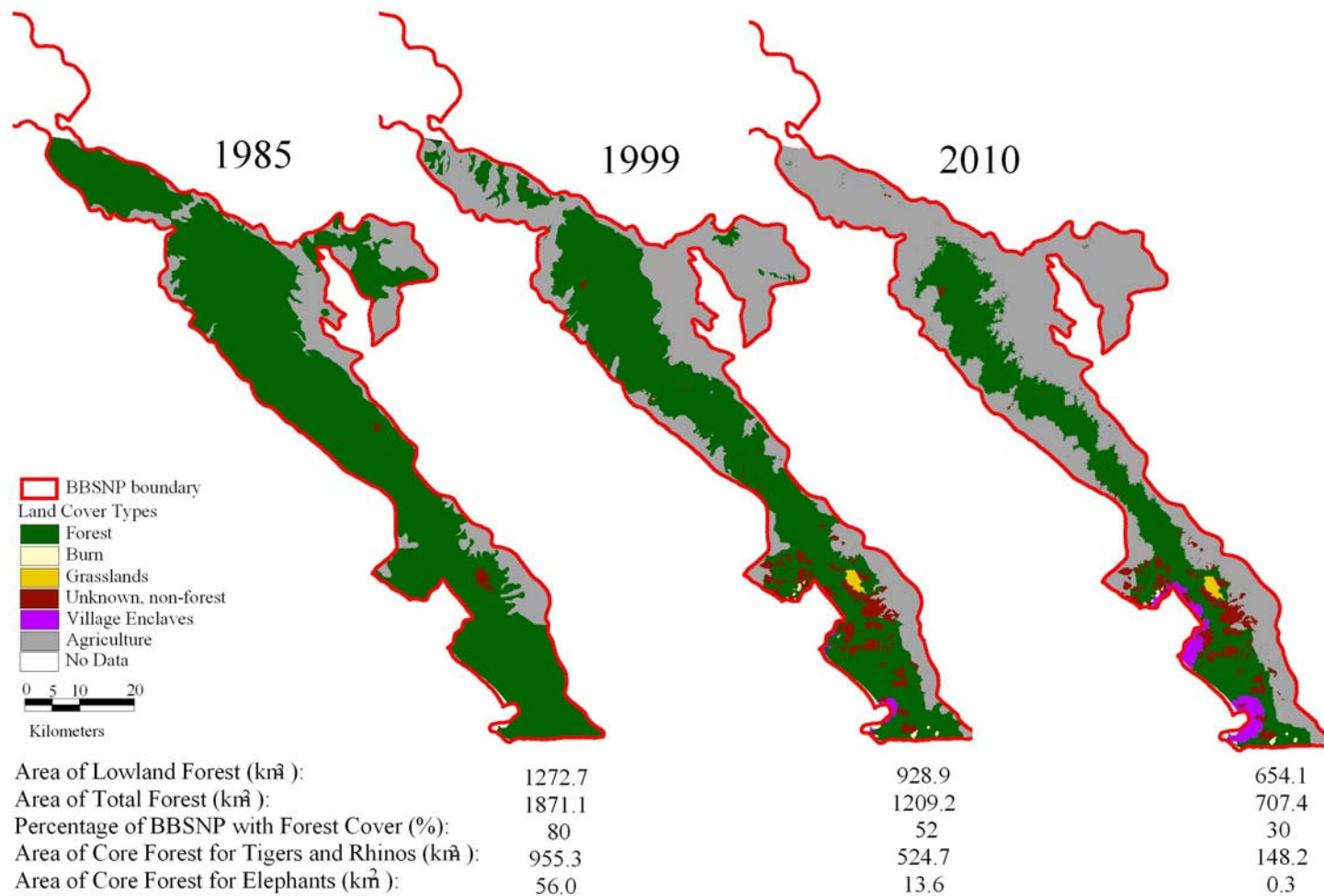


Fig 2.7. Forest cover changes in Bukit Barisan Selatan National Park and the projection of distribution of land cover in 2010 (From Kinnaird *et al.* 2003).

CHAPTER 3

PATTERNS OF CROP RAIDING BY ELEPHANTS ADJACENT TO TWO NATIONAL PARKS IN SUMATRA, INDONESIA¹

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ABSTRACT

I documented crop raiding around Bukit Barisan Selatan National Park (BBSNP) and Way Kambas National Park (WKNP). I quantitatively measured the actual area damaged and identified the pattern of crop raiding around the two parks. I found no correlation between crop raiding incidents and rainfall in these two parks. Peak of crop-raiding incidents were correlated with maize harvest period and one month before rice harvest period. The most damaged crops were bananas, rice, maize and cassava. Mixed groups of elephants were responsible for most of the crop-raiding incidents in both parks. Total economic loss during June 2000 to May 2002 was estimated to be about \$12,000 for 20 villages and the maximum loss for a single village was about \$2000. My research demonstrated that crop raiding by elephants was minor by regional crop production standards, but because of small farm sizes and localized impacts, individual damage to farmers was significant.

INTRODUCTION

Crop raiding by elephants is the major type of human-elephant conflict on Sumatra. Elephants often depredate crops because of (1) the decline in food quality in their habitat (Osborne 1998), (2) human settlements sometimes block their migration corridors (Wambwa *et al.* 2001), and (3) as an extension of optimal foraging strategies (Sukumar 1990, Hoare 1999). Crop raiding by elephants can cause catastrophic damage for some farmers (Naughton-Treves 1998). The size and perception of the problem however, varies widely and there is often disagreement as to the actual amount of damage. Damage varies spatially and the farmer's perception of damage is often different from the actual damage (Naughton-Treves 1998). Furthermore, crop raiding by elephants is believed to be site-specific therefore, information of

crop raiding on particular sites is necessary to develop management strategies in order to mitigate the problem (Chapter 2).

On Sumatra, Indonesia, Asian elephants are in conflict with farmers around the few remaining elephant refuges (Santiapillai and Jackson 1990). High rates of deforestation, encroachment into protected areas, and an increasing human population all exert pressure on elephant populations. In Lampung Province, for example, only 10% of the original forest remains and elephants are concentrated in just two or three forest blocks (Hedges *et al.* in review). Two of the three remaining forests blocks are National Parks (Bukit Barisan Selatan National Parks-BBSNP and Way Kambas National Parks-WKNP). These two national parks are also ranked in the top five-priority areas for elephant conservation on the island (Santiapillai and Jackson 1990). A recent study showed that the elephant population in BBSNP is estimated as 498 (373-666, 95 % CI) individual, compared to 180 in WKNP (144-225, 95% CI) elephants (Chapter 4). These estimates suggest that elephant populations in these parks are internationally significant compared to other elephant populations in southeastern Asia. Unfortunately, elephant population in these two parks is under severe threat due to the poaching and conflict with humans around their habitat (Santiapillai and Jackson 1990).

During the past few years, crop raiding has become a serious issue in the farmland adjacent to these parks. However, quantitative data on the extent of crop raiding in the vicinity BBSNP and WKNP are very limited. The pattern of crop raiding and magnitude of severity is poorly documented. In order to develop effective management strategies to mitigate crop raiding around elephant habitat, information on crop raiding patterns is necessary. In this study, I (1) examined the relationship between the frequency of crop raiding and the pattern of rainfall and crop development, (2) determined the major crops damaged and size of the damage compared to

the relative abundance of crops around the park boundaries, (3) identified types of elephant groups mostly raid crops, and (4) estimated total economic loss caused by elephant.

METHODS

Study Area

The study was conducted in two national parks (BBSNP and WKNP) in Lampung Province, Sumatra, Indonesia. BBSNP is ranked among the top four priority areas for elephant conservation by The World Conservation Union, IUCN (Santiapillai and Jackson 1990) and is the third largest of these areas (3,568 km²). The park is located in southwestern Sumatra (lat 4°31'-- 5°57'S, long 103°34'-- 104°43' E) and administratively lies in the provinces of Lampung and Bengkulu. Altitude ranges from 0 m to 1893 m above sea level and annual rainfall is 3,400–4,200 mm per year. The vegetation types within BBSNP are lowland and mountain tropical rainforest. BBSNP is also recognized as a primary watershed for almost all of southwestern Sumatra (Food and Agriculture Organization 1981). However, due to their linear narrow shape, the park is vulnerable to disturbance from outside of the park such as illegal logging, poaching and encroachment. Furthermore, lack of buffer zones, and the presence of agricultural enclaves in the Parks, provides many opportunities for human-elephant conflicts. The elephant population in the park was estimated to be about 500 elephants (Hedges *et al.* in review).

WKNP is located in eastern part of Lampung Province. The park is 1,235 km² and the typical vegetation types are tropical lowland and swamp forest. Some of the park was logged in the 1960's, so most of the park is relatively degraded. However, the park has still been categorized as the second highest priority area for Sumatran elephant conservation by The World Conservation Union, IUCN (Santiapillai and Jackson 1990). The park is located in Southeast Sumatra (lat 4°62'—5°26' S and 105°54'—105°90' E). Altitude for the entire Park is <50 m

above sea level. Annual rainfall is 2,000 – 3,000 mm year. Total length of the Park boundary is estimated about 227 km. About 148 km of the park boundary bordered with 34 villages around the park. The elephant population in the park was estimated to be about 200 elephants (Hedges *et al.* in review). The government of Indonesia established the Elephant Training Center (ETC) in the southeastern area of this park in the 1980's, to keep all “problem elephants”. These “problem elephants” were captured as a result of human-elephant conflict in other areas of Lampung Province. The “problem elephants” were then tamed and trained at ETC for tourism purposes. The ETC in WKNP is known as the largest in Sumatra, and during my study period (2000-2002) it held about 100 elephants.

BBSNP and WKNP also are known to contain other endangered large mammals. Both parks contain significant populations of endangered large mammals such as; Sumatran rhinoceros (*Dicerorhinus sumatrensis*), Malayan tapir (*Tapirus indicus*) and Sumatran tiger (*Panthera tigris sumatraensis*) (O'Brien *et al.* 2003).

Crop damage assessment

During June 2000--September 2002 crop damage incident reports from around BBSNP and WKNP were collected. Personnel from an existing local non-governmental organization (NGO), called ‘Problem Animal Recorders’ (PARs) were trained to assess crop damage by elephants in every village around BBSNP and WKNP. Three teams (two teams in BBSNP and one team in WKNP) visited the villages around the park regularly and measured the damage from any incidents reported by farmers. To maintain consistency in data collection, sampling protocol for quantifying crop damage was developed. Each crop damage incident was categorized as an independent event. I used a similar definition of an independent event to that described by Naughton-Treves (1998). Independent crop damage events were defined as a single

for any occasion, when an elephant crossed the park's boundary, entered farmland, and damaged crops at a particular time. Crop damage area was measured in square meters and the number of trees for perennial crops were recorded and then translated into total area damaged. The details of damage assessment varied for different crops but the general procedure was similar. Crops were grouped as full cover crops such as rice (assessed on a per square meter basis), and row-crops such as maize and cassava (assessed on a per square meter basis) and tree crops such as bananas and coffee (measured on a per 100-meter square basis).

To estimate the damage in an area I used two considerations. I classified the damage as either a trail of damage or an area of damage. Trail damage occurred when an elephant walked through an area and either did not eat, or ate only along the trail (no widespread meandering patterns). This damage was most typical in rice fields. For this type of damage, I measured the trail length and multiplied by 1 meter to estimate the damaged area. If damage was extensive, then I mapped the area damaged to calculate its total area. Date and time of incidents, and herd size and composition also were recorded for each incident. Composition of groups was categorized as mixed groups (elephant groups containing males and females), male groups (groups of elephants containing only male elephants), cow-calf (adult female with infant), and single males. Number of males, females and young also were recorded, if possible. Number of fields damaged by elephants, type of damage (eaten or trampled), and stage of crop damage were recorded. Coordinate position of each crop damage incident also was determined using Global Positioning System (GPS) Garmin II Plus. Coordinate positions of crop damage were then imported into ArcView GIS v 3.20 (ESRI) database to determine distance of each crop damage location to the park boundary.

Crop planting and harvest period

To obtain base data on farming in the vicinity of the national parks, total of 22 villages around BBSNP and all 34 villages around WKNP were selected as target area. Villages within 1 km from the park boundaries in both parks were selected. Data on type of crop planted, amount of area planted, harvest and planting period were collected using interviews of local farmers. I used stratified random sampling to select the target village around BBSNP due to the extensive perimeter around the park boundaries. In the vicinity of WKNP all villages along the park boundary were surveyed during the study period. Approximately, 30 farmers who had crop fields within 1 km of the park boundary were selected randomly. Total number of respondents interviewed in BBSNP and WKNP was 674 and 1,019, respectively. Each farmer was asked what type of crop they planted, time of planting, size of the area planted for each crop, and time of harvest for annual and perennial crops during 2000 to 2002. Monthly rainfall data were obtained from four stations in BBSNP and two stations in WKNP and annual rainfall amount was calculated for each park.

Economic loss of crop raiding

Direct economic loss of crop raiding was estimated from the total potential yield/m² multiplied by the area damaged. In order to better estimate the direct financial loss to farmers, local market prices of crops around WKNP were used. Total economic loss in 20 villages during the study period was estimated. Maximum economic loss for each village also was calculated. A correction factor (1.67) for extrapolation was used to provide an estimate for the target area (20 villages). Total economic loss for three major crops (rice, maize and cassava) also was estimated.

In order to understand how severe the economic damage caused by elephants was to the farmers, I used potential crop production of rice, maize and cassava as comparison to the loss by elephant damage. Since rice, maize and cassava represented 97.34% of crops planted around WKNP, I assumed the economic loss of these types of crops would be reliable estimates of the economic loss caused by crop raiding elephant around the park. I used data on maximum yield for each crop produced around the area and local market prices for each crop to calculate mean revenue from these three type crops. Data were collected from East Lampung Agricultural office. Finally, I calculate percent economic loss because of crop raiding by comparing mean economic loss by crop raiding per village and mean revenue per village in three major crop types (rice, maize and cassava).

RESULTS

Rainfall, crops planted and harvest period

Crop damage by elephants in both BBSNP and WKNP was not correlated to the monthly rainfall (Figure 3.1). There was no difference in mean number of incidents during dry seasons and wet seasons in either park ($n = 28$, $Z = -1.735$, $P < 0.08$ in BBSNP and $n = 28$, $Z = -0.554$, $P < 0.58$ in WKNP). In general, both parks showed similar patterns of wet and dry seasons. Despite a lack of a relationship between rainfall and frequency of crop raiding around the parks, the proportion of incidents near major rivers was relatively higher during the dry seasons (47.3%, $n = 205$) compared to the wet seasons (28%, $n = 189$) in WKNP. Dry seasons occur normally in March through September, with the peak in August. The wet season occurs from the beginning of October through late February, with the peak in December or January. Despite the fact that there was no relationship between number of crop damage incidents and rainfall in WKNP, peak

crop damage incidents (during the study period) occurred during the peak of wet seasons (January 2001 and 2002, Figure 3.1).

Elephants damaged at least 31 species of crops around BBSNP and WKNP. Most of the crops were consumed except a few species like chilies, pepper, and coffee, which were mainly damaged by trampling. Major crops damaged by elephants in BBSNP were bananas (33.2%), cassava (12.5%) and rice (14.4%, Figure 3.6). Damage was reported sporadically for other vegetables such as tomatoes, various beans, and leaf vegetables. In WKNP, rice was the most frequently damaged by elephants (37.8%), followed by cassava (20.4%) and maize (17.9%; Figure 3.6).

Overall, in BBSNP development stage of the crop was related to crop damage with 30.8 % of crop damage incidents occurring on crops ready for harvest; 35.2% were on mature crops, 3.6% were on immature stage crops, and 30.4% were unknown (Figure 3.7). In WKNP crop damage by elephants showed similar patterns. Most of the damaged crops were either at mature stage (47.2%), or were ready for harvest (37.0%). Only 8.4% of the damage occurred at immature stage of crops, and 7.4% were unknown (Figure 3.7).

In WKNP, there was a strong correlation between crop damage incidents with certain crop harvest periods. Raiding frequency was significantly correlated with rice harvest month and the peak of raiding occurred one month before harvest (Spearman's $r = 0.633$, $P < 0.01$, Fig 3.2). Raiding frequency also was correlated with maize harvest period (Spearman's $r = -0.395$, $P < 0.05$, Fig 3.3), however, the relationship was negatively correlated with peak of raiding during the maize harvest period. In contrast, raiding frequencies on cassava did not show any relationship to the cassava harvest period (Spearman's $r = -0.278$, $P < 0.173$, Fig 3.4).

Regression analysis showed that linear relationship only occurred between frequencies of crop

raiding in rice and the one-month period before rice harvest ($n = 27$, $F=8.345$, $r^2 = 0.243$, 26 df, $P<0.01$). However, there was no linear relationship between crop raiding in maize and maize harvest period ($n=27$, $F=1.52$, $r^2 = 0.05$, 26 df, $P<0.23$). Crop raiding in cassava also showed no linear relationship to the cassava harvest period ($n=27$, $F=1.97$, $r^2=0.07$, 26 df, $P<0.173$).

Total area damaged for the three major crop types (rice, maize and cassava) during the study period and using the 1.67 correction factor was estimated at 361,854 m² (36.2 ha). Mean area per incident for rice was estimated at 1,142 m² (160.0 SE, $n=119$), maize was 783 m² (99.7 SE, $n=50$), and cassava 681 m² (13.0 SE, $n=61$, Table 3.1).

Group pattern of raiding elephants

Around BBSNP, mixed groups were responsible for 70.7% of incidents, single males 20.4%, male groups 3.7%, cow-calves 4.4%, and unknown 1% (Figure 3.8). Mean elephant group size was estimated at 8.6 individuals (0.4 SE, $n = 208$). A maximum of 16 individuals was recorded in one single incident around BBSNP. The mean male group size responsible for the crop raiding in BBSNP was 3.6 (0.9 SE, $n = 7$).

Around WKNP, mixed groups also were responsible for the most incidents (62.9%). Single males were responsible for 26.4%, male groups for 4.31%, cow-calves 1.52%, and unknown was 4.8% (Figure 3.8). Mean group size in WKNP, was 5.1 individual, which was statistically lower than in BBSNP (0.3 SE, $n = 444$, $Z = -6.98$, $P < 0.001$). Maximum number of elephants that had been recorded in one single incident in WKNP was 30 individuals, which was almost twice as higher than BBSNP. Mean male group size that was responsible on the crop raiding in WKNP was 7.4 (1.6 SE, $n= 17$).

There was no difference between mean sizes of male elephant groups in WKNP and BBSNP ($n = 24$, $Z = -9.26$, $P< 0.354$). The comparison of the mean group size during crop

raiding incident at dry season and wet seasons also showed no significant difference in WKNP ($n=197$, $Z = -1.83$, $P < 0.07$). However in BBSNP, mean elephant group size in dry seasons was significantly higher than wet seasons ($n=208$, $Z = -4.90$, $P < 0.001$).

Economic loss of crop raiding

The estimate of economic loss of crop raiding by elephants for this study was derived for a portion of the study around WKNP, because it provided a better estimate of size and area damage. Easier access into most of the villages in the vicinity WKNP allowed me to accurately measure damage as soon as incidents took place. Total value of the losses in 20 villages between June 2000 and May 2002 was estimated at \$2,144 USD (Rp. 8,700/dollar) and maximum loss per one village was estimated at \$2,091 USD. Total financial loss for cassava was estimated at \$3,268 USD, with mean loss per incident of \$272 USD. Total financial loss for rice and maize was estimated at \$7,606 USD and \$1,293 USD, respectively. Mean financial loss per single incident for rice and maize was estimated at \$507 USD and \$129 USD.

Mean planted area for rice per year per village around WKNP was 12.95 ha (1.34 SE, $n=34$) and mean planted for cassava and maize is 14.09 ha (2.26 SE, $n=31$) and 8.51 ha (1.32 SE, $n=30$), respectively. Mean revenue from three crop types were estimated using maximum yield for each crop produced per ha and local price for each crops per kg. For rice, mean revenue generated per village from the harvest was \$5,274 USD, cassava was \$7,291 USD, and maize was \$1,945 USD. By comparing mean revenue generated from each crop type per village to the mean loss for each crop type per village, the proportion of economic loss was estimated for rice to be 9.61%, cassava was 3.73% and maize was 6.65% per village (Table 3.2).

DISCUSSION

Rainfall, crop planted and harvest period

Both in BBSNP and WKNP, frequency of incidents in dry seasons and wet seasons did not show a clear difference. There are several possible explanations to support this result. First, food quality in the park was probably not significantly different during dry and wet seasons. As a result, elephants in the park did not have to raid crops for alternative food resources. Osborne (1998) claimed that crop raiding by elephants could be triggered by a decline of food quality within the park, which normally occurs during the dry seasons. It seems this pattern did not occur in BBSNP and WKNP. Second, there might be no clear difference in the crop-planting season during the dry and wet seasons around the park. Farmers are able to plant their crops during the dry season because of the availability of irrigation systems in the most of the villages around WKNP. In this case, crop abundance around the park would be relatively stable during both the dry and wet seasons. This situation is quite different compared to the crop-raiding pattern in Africa. In eastern Zambezi, Zimbabwe, dual-seasons in crop raiding by elephants were known to occur. The dual-seasons in crop raiding were caused by the numerous amount of crop planted during the wet season due to water availability (Parker and Osborn 2001).

The higher number of crop-raiding incidents near major rivers during dry seasons in these study probably occurred because of the lack of water availability in the park. When water is scarce during the dry season, elephants might prefer to stay near an area where water is abundant, such as major rivers. Elephant need to consume about 80–160 liters of water per day, (Sukumar 1989) so it is understandable why they spend most of their time near the major rivers during dry seasons. In WKNP, there are two major rivers dividing the park and agriculture area, Pegadungan River in the North and Penet River in the South. Crop fields near this river are more

vulnerable to the crop raiding, because elephants might be attracted to crops that are available near the river while searching for water. In Eastern Zambesi Valley, Parker and Osborn (2001) reported a similar pattern of crop damage by elephants.

Crop damage incidents in WKNP were correlated to the harvest period of maize and rice. Elephants preferred maize and rice probably because of the high protein contents in these crops (crude protein dry matter for maize = 12% and rice in the grain stage 10.4%; Sukumar 1989). Rice also is known to have relatively high sodium contents in the mature stage (0.36mg/g; Sukumar 1989). Sodium is one of the most important minerals for elephants beside calcium. Adult elephants require an estimated 75-100 g of sodium daily (Sukumar 1989). Interestingly the correlation between maize harvest period and crop raiding was shown to be negative. This interesting phenomenon is probably because farmers successfully defend their crop field during maize harvest, so elephants miss the peak harvest and damage fields after most of the maize has been harvested. Therefore, number of crop-raiding incident was very low during maize harvest. Most of the farmers (> 90% of total) harvest maize located in the area with a large river as a boundary to the park; therefore it may be relatively easier to prevent elephants from crossing this natural barrier along the park boundary.

In contrast, cassava is planted and harvested without strict periodicity, and harvest times are not synchronized. Raiding, however showed a periodicity, apparently unrelated to harvest period of the crop. Comparing the raiding frequencies for the three crops, we see that the pattern of cassava raiding follows the pattern of the rice and maize raiding. This suggests that the periodicity in the rice and maize harvests may influence the frequency of elephant raiding, but that cassava is possibly a “fall-back” crop encountered when elephants seek the more palatable maize and rice (Fig 3.5).

Maize was not a principal target of crop raiding in BBSNP because most farmers in BBSNP planted coffee, pepper, and chili around the park boundaries. However, damage to these three crop types was considered to be relatively high, and most of these crops were trampled and not eaten. Since elephants do not consume coffee, pepper, and cocoa, harvest period for these three crops was not correlated with the frequency of incidents. This crop might not be attractive to elephants even during the harvest period. Bananas, rice and various vegetables were more likely to be principal target crops raided by elephant around BBSNP. Rice also was planted to some extent in BBSNP, but since the rice fields were largely interspersed, were relatively small in scale and were not harvested at the same period, the effect of rice-harvested period in BBSNP was hardly detected. The similar situation also was found in Southern India, where most crop raiding occurred during maize harvest period and finger millet (Sukumar 1989). In WKNP, the picture was similar, with rice being the principal target, but cassava and maize also was regularly damage by elephants. Local farmers have made the decision to grow cassava in preference to the more lucrative maize or rice crops due to the elephant-raiding problem. No bananas and coconuts were planted during the study period, but existing banana and coconut trees were attacked.

Based on an interview survey in 1997, elephants in WKNP reportedly damaged at least 45 ha of rice, maize, ground beans and cassava (Nyhus *et al.* 2000). These estimates appeared to be about 20% higher than this study for the relatively same crop type. During my study ground beans represented less than 1% of damage from overall crops because it was not a major crop planted around WKNP. Even if I included ground beans in the calculation the total damage was still far less from reported by Nyhus *et al.* (1997). It seems that over an interval of a few years there has been an apparent major decline in crop raiding in WKNP, but local farmers do not

support this idea. The most likely explanation for the difference between the data sets is the well-known problem of interview surveys. The difference may arise from farmers over-reporting the size of the problem during the interview survey, possibly in an attempt to elicit action from the government.

Typical damage area for three major crops planted in WKNP was about 0.1 ha. However, damage in excess of 0.5 ha has been recorded in a single incident. These damaged areas are relatively small, but the typical planting area is also small, so there is a possibility of a farmer losing half of his crop, or even more, in a single incident. Since only individual farmers usually suffer from crop raiding by elephants, the problem has never risen above the regional level. As a consequence, the central government does not recognize crop raiding by elephants as a crucial problem, and the issue has never been prioritized as a conservation concern by the government. Data from the government agricultural services show that insect pests, particularly locusts and rodents are a far greater cause of rice losses than elephants. In 2002, data for six districts around BBSNP showed that rice damage by insect and rodents was estimated at 7,388 ha and 1,635 ha, respectively; the equivalent figures for 2001 were 6,344 ha and 1,092 ha. For the same districts, government estimated that elephant damaged just 30 ha and 20 ha of rice in 2000 and 2001 (West Lampung District unpub. data).

Group pattern of raiding elephants

In general, crop-raiding patterns by group type of elephants in both parks showed a similar pattern. Most of the crop raiding was dominated by mixed groups, and followed by single males. This result is quite different compared with the Sukumar study in southern India (Sukumar 1989), which suggested that bull elephants raided crops more frequently than did family groups during the year. Furthermore, the study in India suggested that crop raiding by

elephants is suspected to be part of the male optimal foraging strategy (Sukumar and Gadgil 1988). Several other studies in Africa also suggest that male elephants, either individual bull or male groups represent the main type of crop-raiding elephants. A study in Liwonde National Park, Malawi showed that individual bulls or male groups were responsible for 85% of the crop raiding (Bhima 1998). In northern Sebungwe, Zimbabwe, about 79% of the crop raiding incidents by bull elephants also were documented (Hoare 1999).

There are several possible explanations why the situation of crop raiding in Sumatra was different from other areas. First, there is a possibility that population structure of the Sumatran elephant in BBSNP and WKNP is different than in other regions. It is quite likely that the composition of adult males in both parks is lower compared with the other region. If the composition of adult males in the population is low, then the competition among male elephants for breeding within the population will also be low. If this is the case, adult male elephants do not have to invest in the high risk foraging strategy of raiding crops in order to maximize their reproductive success. In other words, even though the “high-gain, high-risk” theory is considered important for elephants (Sukumar 1988), adult male elephants in Sumatra may not need to adopt that foraging strategy. Alternatively, there is a possibility that crop raiding is primarily an effect of the seasonal movement of elephants, especially in BBSNP. Over a 100 crop-raiding incidents occur in the Sekincau area (north eastern part of BBSNP) in May 2002. A single herd of elephants containing 16 individuals continuously raided farmer’s crops along the boundary over a period of two weeks. The same situation occurred again in May 2003, when a herd of 14 elephants damaged the same area. It is too speculative to say that these are the same elephants (it is impossible to recognize them individually), nonetheless there is a possibility that they might be the same herd. A similar pattern also was found in southern India and Africa,

where elephant herd movement was strongly correlate with frequency of raiding (Sukumar 1990, Tchamba 1998).

The dynamics of elephant group size during crop raiding between dry and wet seasons also showed a different pattern in BBSNP and WKNP. In BBSNP, mean group size in dry season incidents was significantly higher than in wet seasons. A possible explanation for this phenomenon is that elephants have to form large groups to maximize their safety when they travel far from the park boundary to raid crops during the dry season. Elephants in BBSNP were found to travel almost 8 km from the park boundary to raid crops during dry seasons. In contrast, most of the incidents in WKNP occurred less than 1 km from the park boundaries (see Chapter 2). In this case, we can conclude that elephants in WKNP did not have to travel far from the park to raid crop. As a result, if elephants chased by farmers to defend their crops, they can easily return to the park for safety. Thus, forming large groups is not considerably beneficial for safety. This result corresponds with other studies of elephant group dynamics in Africa and other part of Asia. Elephant group size is reportedly affected by rainfall, vegetation structure and elephant density (Leuthold 1976). Furthermore, young and inexperienced females and juveniles of both sexes have been reported to join an older female and form a larger group to gain knowledge from older females about resources and for security reasons (McKnight 2000). Bull elephants also are reported to have a tendency to form a large group to increase the safety during raiding in India (Sukumar 1989).

Economic loss of crop raiding

The economic loss of crop raiding is certainly one of the most important aspects that need to be assessed before a mitigation scheme is developed. However, calculating the economic loss accurately is quite complicated. This study shows that the estimate of direct economic loss from

crop raiding is relatively small in WKNP. Actual economic impact of farmers may be higher in some cases because there were some indirect costs associated with crop raiding by elephants. An indirect cost that might occur is the need for people to guard their crop field during the night or some could be more extreme as children were unable to attend school because their parents required their assistance in chasing of elephants (Thouless 1994, Tchamba 1996, Naughton-Treves 1998). The results of this study showed that economic loss due to the crop raiding by elephant in WKNP is less than 10% of mean farmer's revenue (per village). If the total economic loss of the crop raiding by elephants is inexpensive on a regional scale, then a compensation program might be a sufficient way to solve crop raiding by elephants in WKNP and BBSNP. This type of scheme has been suggested in several areas in Africa and Asia because it is believed that it could increase the tolerance level of local farmers toward elephants (Sukumar 1989, Tchamba 1996). However, the sustainability of this program is still questionable (Hoare 1995). Naughton *et al.* (1999) suggested that compensation should be integrated with two conservation guidelines. First, local farmers should support the idea of providing a buffer zone around the park and allow the area to return to the late forest succession. Second, local farmers can help to reduce poaching and illegal logging activity within the park by not giving access to poachers. Whereas this guideline is very useful, I would argue it is not comprehensive enough to maintain the sustainability of the program. In addition to the suggestions of Naughton *et al.* (1999), I believe farmers around the park should also be involved in a crop mitigation scheme. Small local "crop protection units (CPU) " should be developed at a community level and managed by farmers. Crop protection units would be more effective if they also were facilitated by international conservation NGOs. The teams would be responsible for driving elephants back in to the park using "improved" traditional methods. Such

“improved” traditional methods have been used in the Mid-Zambezi Elephant Project in Zimbabwe and have effectively mitigated crop raiding by elephants (Osborn and Parker 2002).

A source of compensation and the associated technical aspects of the implementation of a compensation scheme are also recognized, as being crucial aspects. I argue that a compensation program would be more feasible if it is set up as a local, self-sustained, insurance scheme. Management of the insurance should be set up based on the “compromise” and should involve various stakeholders. There would be at least three important stakeholders: farmers, government and conservation NGOs should be involved as a part of the implementation. Each party should be involved in providing premiums, setting up an independent team to assess the damage, and creating and establish compensation payment mechanism.

MANAGEMENT IMPLICATIONS

Crop raiding is major part of the human-elephant conflicts in Sumatra and is also recognized as the biggest threat to the wild elephant population, even though the actual scale of damage is rather small scale. Crop raiding also generates resentment, which can lead to the local people killing “problem elephants” by poisoning them. Currently there are no effective management strategies applied in BBSNP and WKNP. In some areas along the boundary of WKNP, the National Park Service, in collaboration with local farmers, has created trenches to prevent elephants from crossing the park boundary. However this mitigation scheme is not effective in reducing crop raiding. During the rainy seasons elephants can easily destroy trenches and along the wetland areas trenches are very difficult to build. Capturing “problem elephants” by government officials also is commonly done to reduce the conflict in both parks. Large numbers of “problem elephants” are captured from the wild by the government and placed in the ECC. There are about 400 “problem elephants” in six centers across Sumatra. However,

capturing “problem elephants” and keeping them in the ECC does not solve the problem and has a big impact on the wild elephant population.

To mitigate human-elephant conflicts, particularly crop raiding by elephants in BBSNP and WKNP, important issues that have been identified as the source of the problem should be effectively solved. First, habitat destruction such as illegal logging and encroachment within both parks should be stopped immediately. Illegal logging and human encroachment in both parks is predicted to be the major factor of destroying elephant habitat. Encroachment within the park also has been predicted to be responsible for the reducing size of elephant movement areas. Habitat connectivity is very important for large mammals with high mobility like elephant. During 1980-2000 forest cover in WKNP declining to about 12.5% (Hedges *et al.* in review). Furthermore, local farmers have encroached on about 10% of the park during the last five years (Bintoro, Head of WKNP, pers comm.2002). Kinnaird *et al.* (2003) estimated an average loss of forest cover in BBSNP of about 2% per year. A total of 661 sq km of forest disappeared inside the park and 318 sq km were lost in a 10 km buffer, eliminating forest outside the park. The study by Kinnaird *et al.* also predicted that the core area for elephants would be reduced to 0.5% of the remaining forest in 2010. Second, managing elephant habitat by planting natural elephant food should be investigated. In both parks, elephant abundance is often higher in the open area with high abundance of wild bananas (Musaceae) and wild ginger (Zingiberaceae). Improving the heavily degraded habitat within the park by replanting natural elephant food could prevent the elephants from coming out of the park. Third, a new reforestation scheme such as providing forest buffers along the elephant habitat should be conducted in order to increase the area available for elephants. Buffer areas could be planted with the tree such as Damar tree (Dipterocarpaceae; *Shorea sp.*). Damar trees can also provide additional income to the farmers

because their resin is valuable economically. Farmers can harvest damar resin without having to kill the tree. In some areas around BBSNP damar tree have been planted, and the resin from the tree has been harvested traditionally for more than 60 years (*pers obs*). The two species of damar that have been planted in some areas around BBSNP are eye cat's damar (*Shorea javanica*) and stone's damar (*Shorea ovata*), so the trees are able to grow in the area. Fourth, highly palatable crops such as bananas, maize, cassava and rice should not be planted near elephant habitat. The results of this study indicate that elephants are more likely to damage these crops than other crops. Planting alternative unpalatable crops should be investigated and introduced to the farmers. Furthermore, a fair market for alternative crops should be established to support the sustainability of the schemes. I believe management strategies should incorporate and test all the possible options such as describe above and tested around each elephant habitat.

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Table 3.1. Damage (m²) for rice, maize and cassava and comparison with typical planting area around Way Kambas National Park, Sumatra.

Crop	Mean area per incident (m²)	Median area per incident (m²)	Largest single incident (m²)	Typical planting/median area originally planted (m²)
Maize	783.0	615.5	2,670	7,500
Rice	1142.3	470.0	9,001	5,000
Cassava	681.8	297.6	4,860	5,000

Table 3.2. Economic loss due to the crop raiding by elephants in the villages around Way Kambas National Park, Sumatra.

Crop	Mean revenue per village (\$ US)	Mean economic loss per village (\$ US)	Proportion of economic loss (%)	Number of villages (N)
Cassava	7,291.48	272.30	3.73	30
Rice	5,274.55	507.06	9.61	34
Maize	1,945.01	129.25	6.65	31

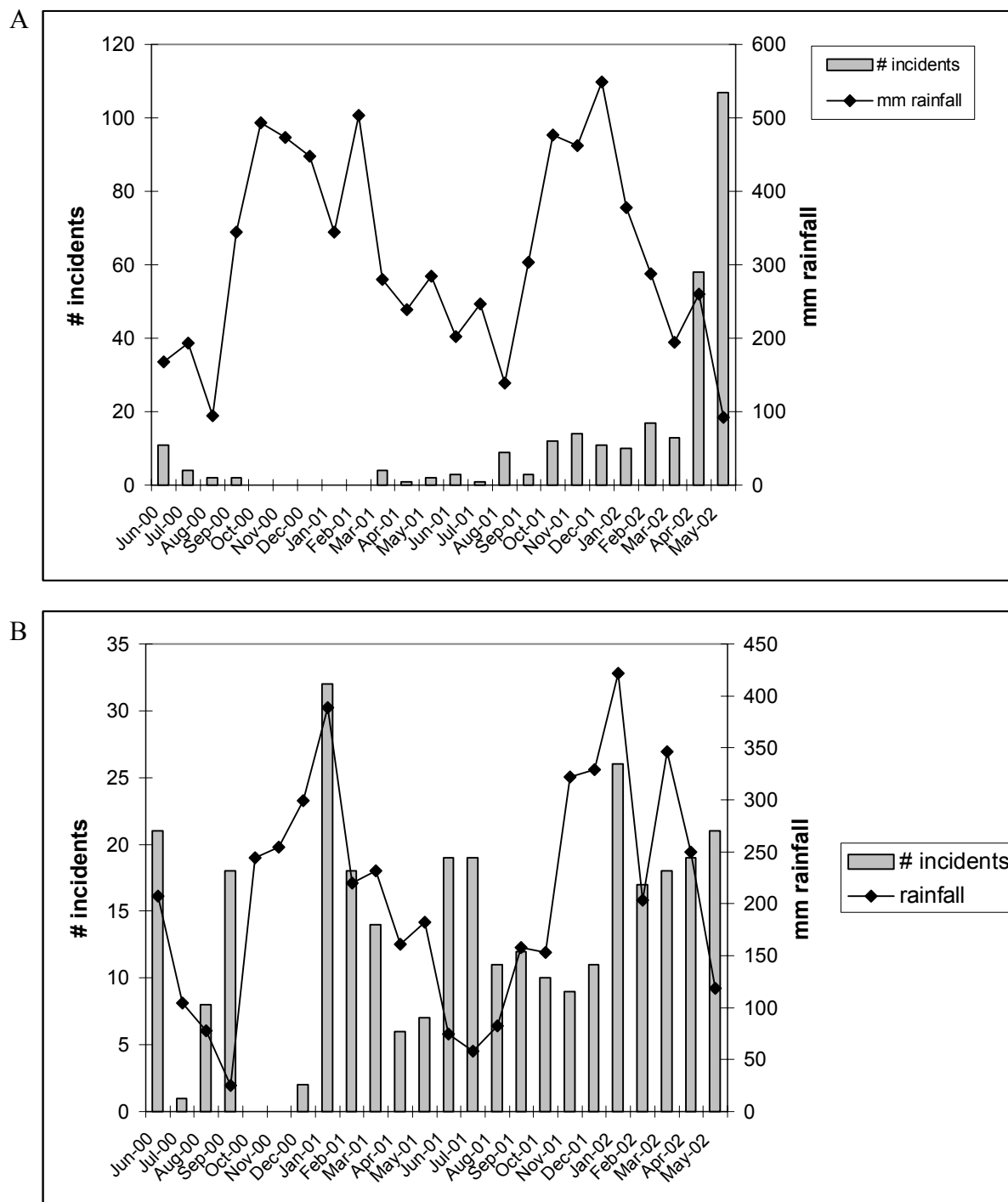


Figure 3.1. Rainfall patterns and frequency crop raiding incidents by elephants in the vicinity of
 a) Bukit Barisan Selatan National Park and b) Way Kambas National Park, Sumatra, Indonesia,
 during June 2000 to May 2002.

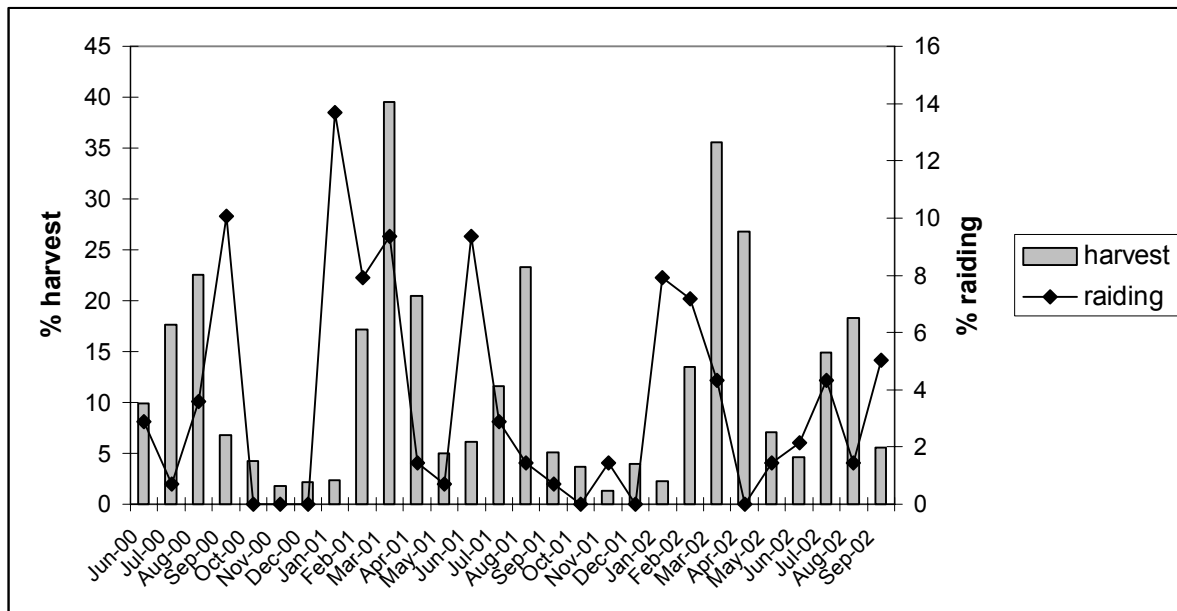


Fig 3.2. Crop raiding frequency and rice harvest pattern in the vicinity of Way Kambas National Park, Sumatra Indonesia during June 2000 to September 2002.

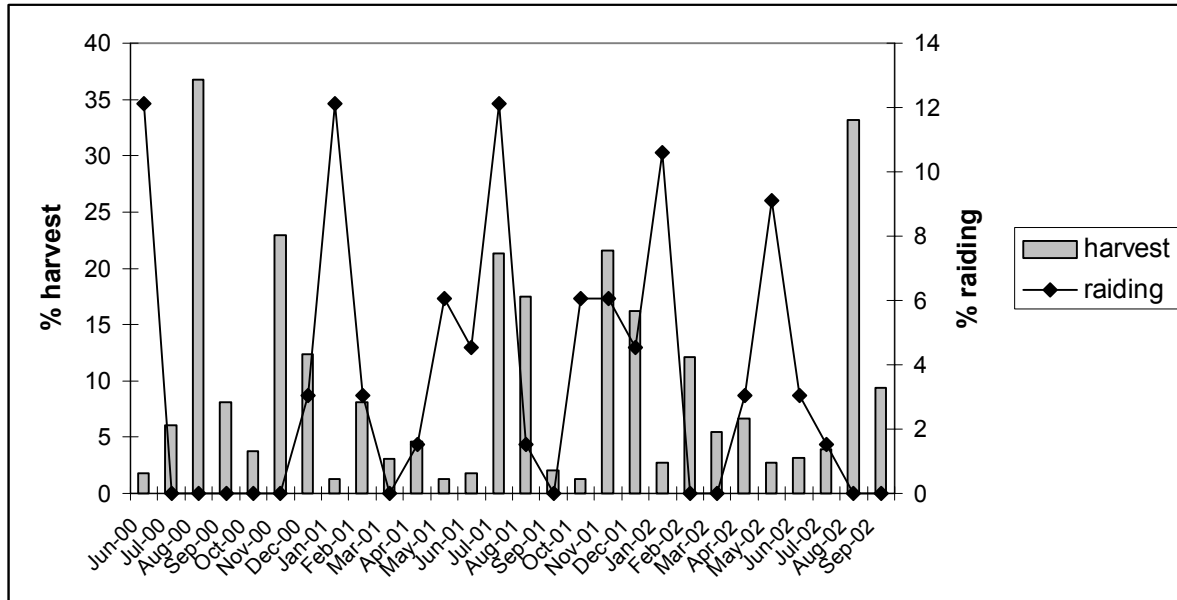


Fig 3.3. Crop raiding frequency and maize harvest pattern in the vicinity of Way Kambas National Park, Sumatra Indonesia during June 2000 to September 2002.

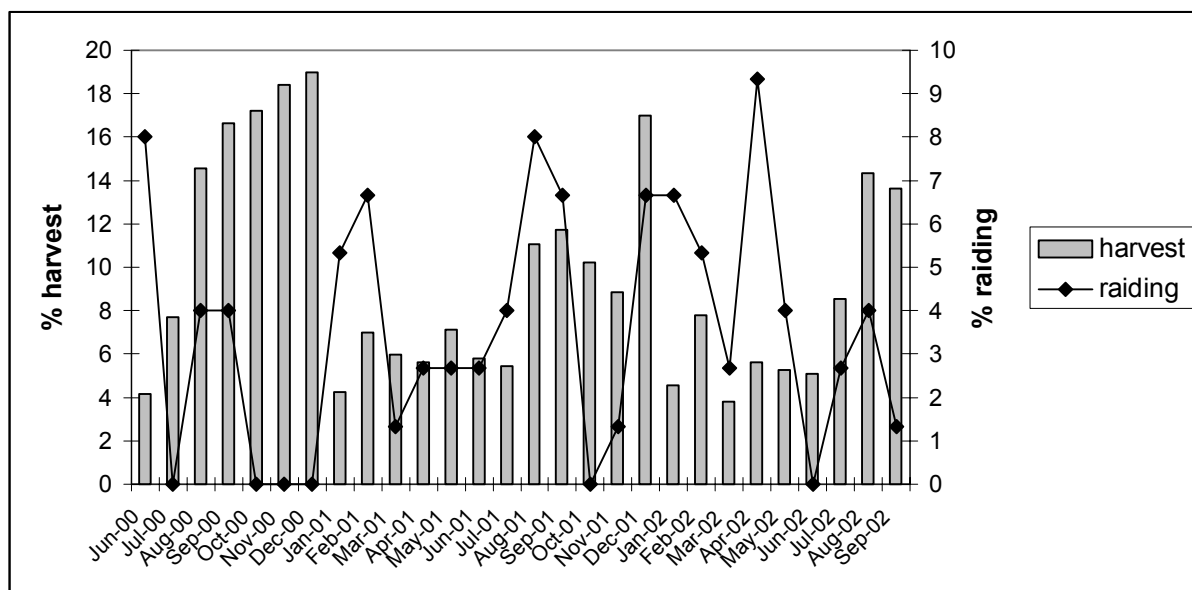


Fig 3.4. Crop raiding frequency and cassava harvest pattern in the vicinity of Way Kambas National Park, Sumatra Indonesia during June 2000 to September 2002.

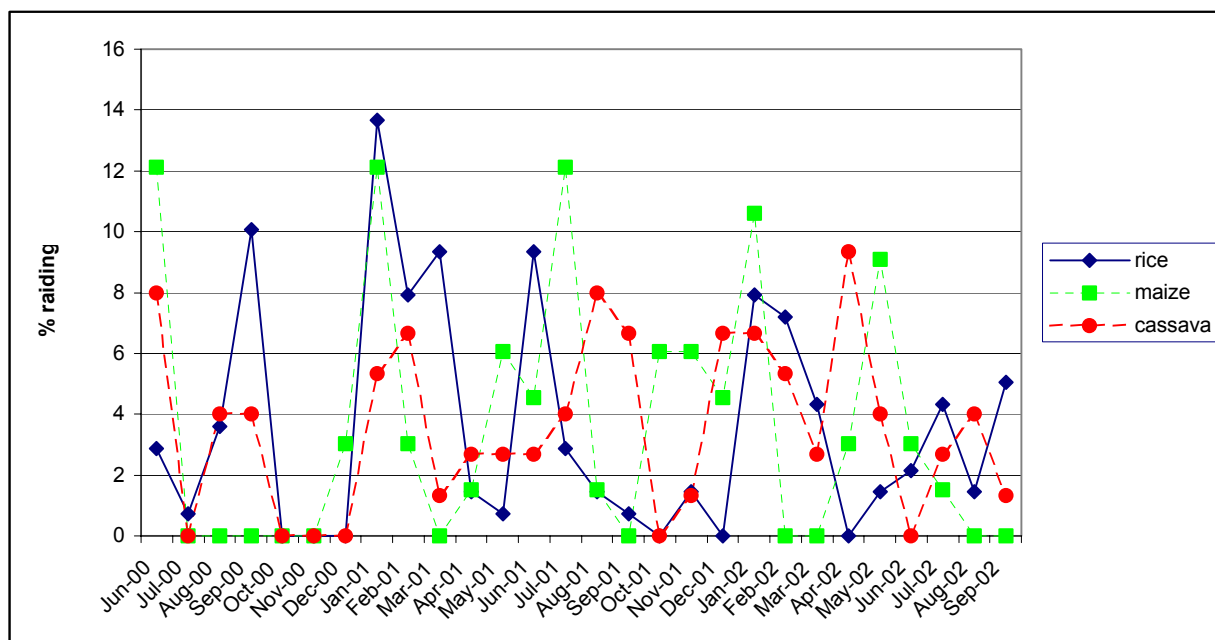
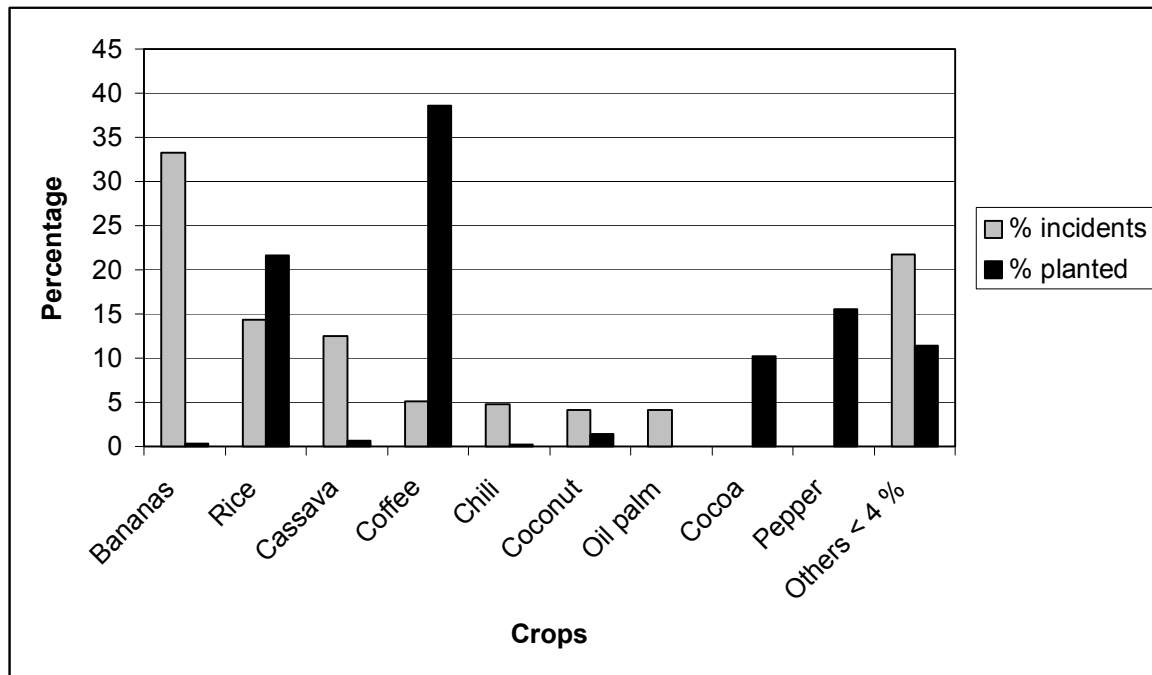


Fig 3.5. Pattern of crop raiding frequency for three different crop types in the vicinity of Way Kambas National Park, Sumatra Indonesia during June 2000 to September 2002.

A



B

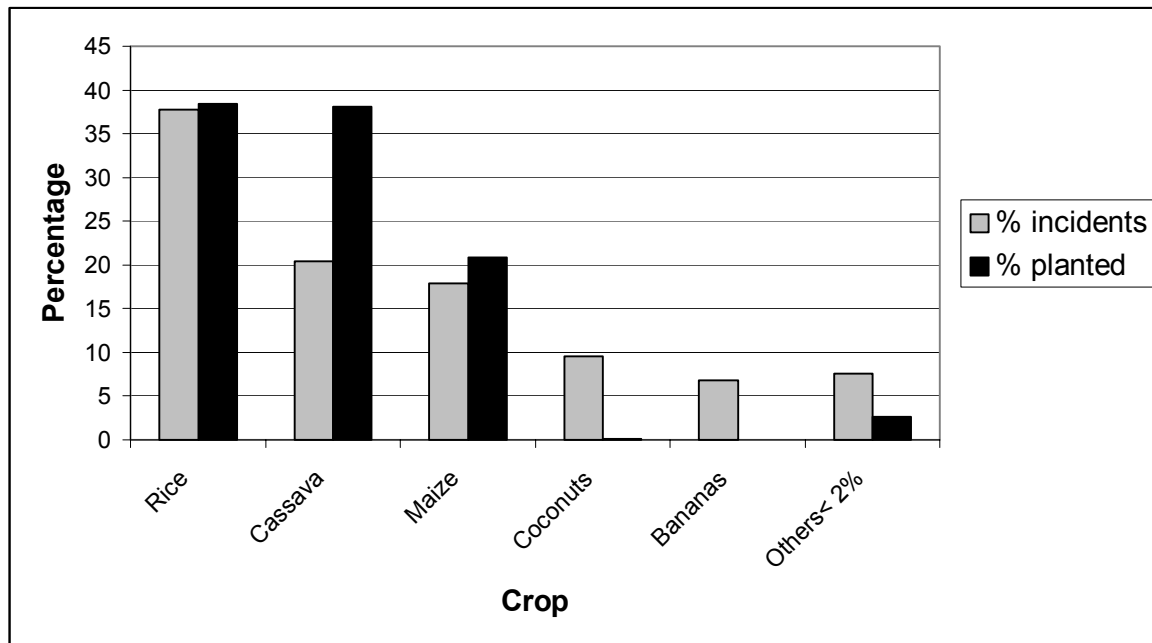


Figure 3.6. Types of crops grown and rates of damage by elephants in the vicinity of a) Bukit Barisan Selatan National Park and b) Way Kambas National Park, Sumatra, Indonesia, during June 2000 to May 2002.

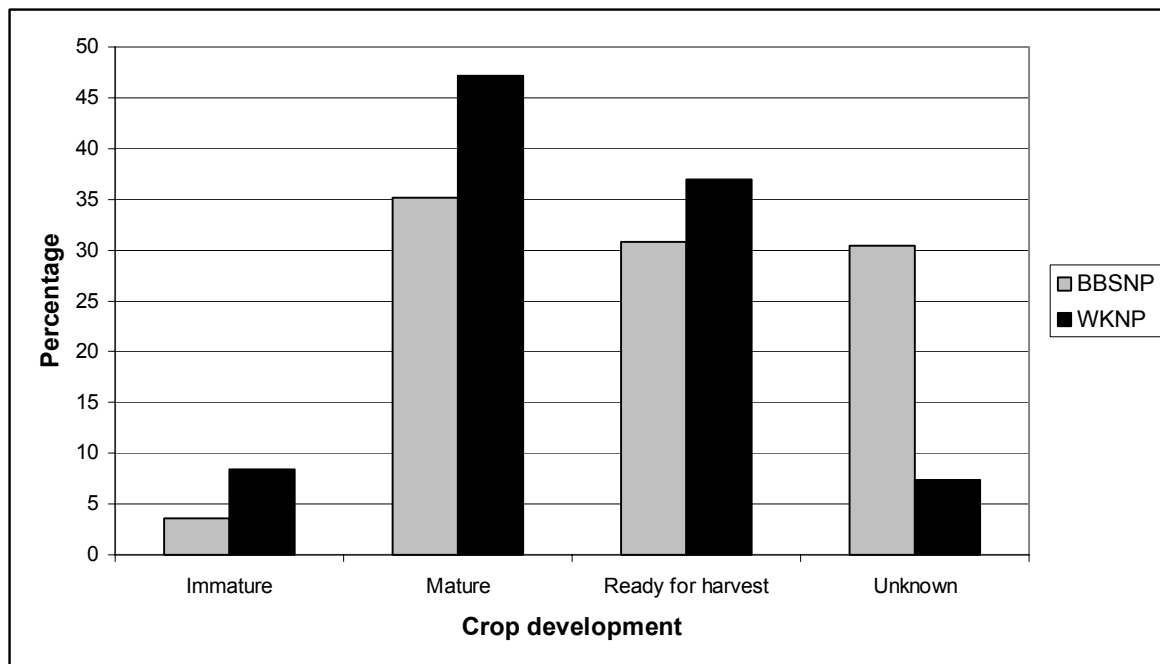


Figure 3.7. Growth stage of crops relative to damage by elephants in the vicinity of Bukit Barisan Selatan National Park and Way Kambas National Park, Sumatra, Indonesia, during June 2000 to May 2002.

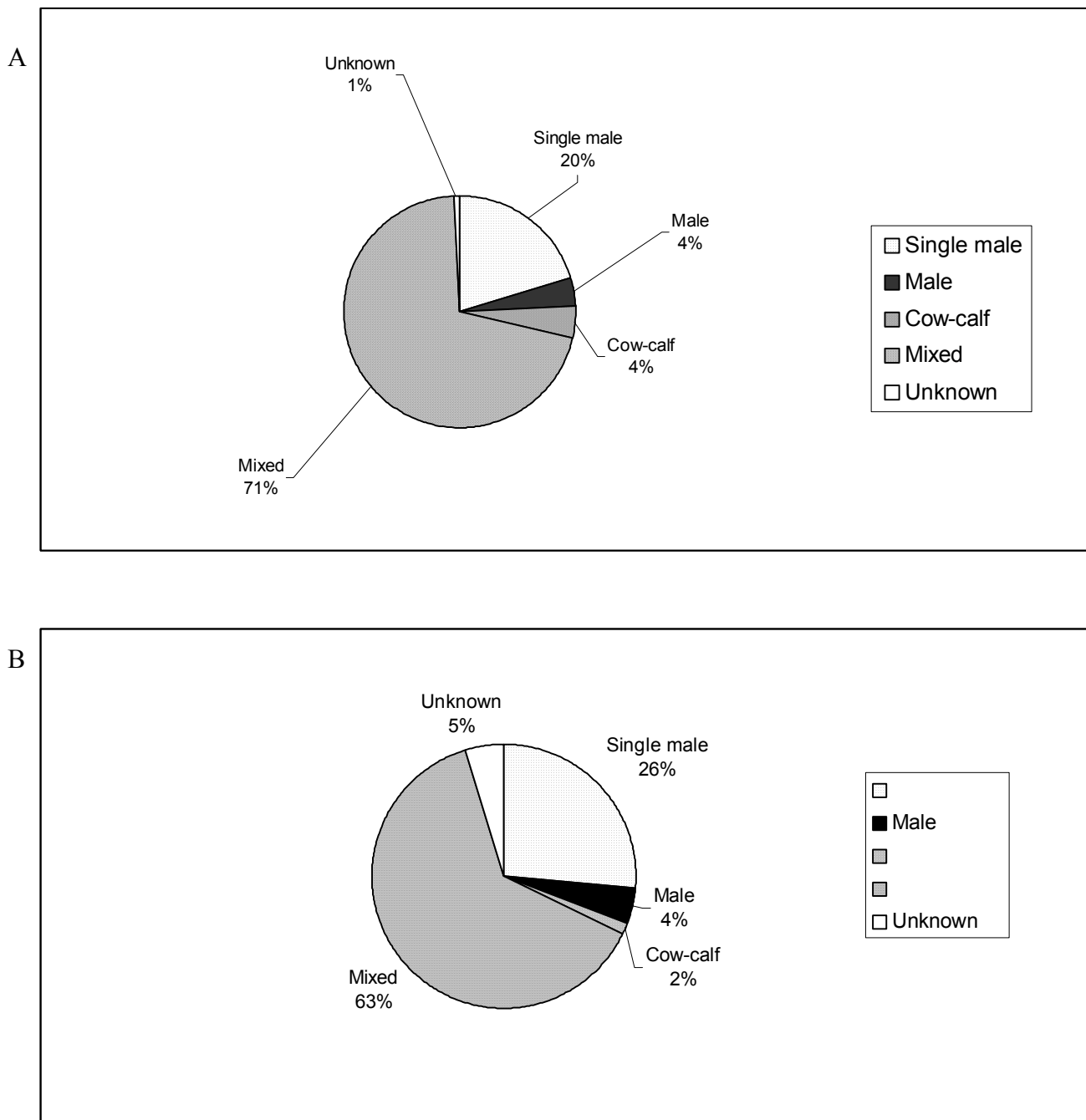


Figure 3.8. Elephant group composition during crop raiding incidents in the vicinity of a) Bukit Barisan Selatan National Park and b) Way Kambas National Park, Sumatra, Indonesia, during June 2000 to May 2002.

CHAPTER 4
POPULATION ESTIMATION AND MODELING THE IMPACT OF POACHING FOR
SUMATRAN ELEPHANT¹

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ABSTRACT

I estimated elephant population size in Bukit Barisan Selatan National Park (BBSNP) and Way Kambas National Park (WKNP) in Lampung province, using dung count method. I developed an elephant population model, and project the population trajectory under three different poaching scenarios (control, low and high poaching) for WKNP. I estimated elephant populations in BBSNP and WKNP to be 498 (373-666, 95% CI) and 180 (144- 225, 95% CI) elephants, respectively. The population models suggested that in ‘control’ and low poaching scenarios, elephant population would increase in the next 50 years. In high poaching scenarios with logistic and constant poaching function, elephant population will be extinct in less than 50 years. The most sensitive parameter in the model was adult reproduction rate and adult survival. In the poaching parameter, logistic poaching function was the most sensitive. I recommend routine population assessment and intensive poaching monitoring should be priority in the management.

INTRODUCTION

The Sumatran elephant (*Elephas maximus sumatranus*) is one of three sub-species of Asian elephants. The species is listed as Endangered in the 2002 IUCN Red List of Threatened Species (IUCN 2002) and is included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; UNEP-WCMC, 2003). Unfortunately, despite the importance of Sumatran elephant populations, there has never been a systematic evaluation of the conservation status of elephant populations on Sumatra. Blouch and Haryanto (1984) and Blouch and Simbolon (1985) estimated populations of Sumatran elephants to be about 2,800—4,800, however, these estimates were not scientifically legitimate because they

were not derived using statistically rigorous techniques and data were extrapolated from one area to another.

During the mid-1980's, Sumatran elephants were believed to exist in about 44 populations on the island (Santiapillai and Jackson 1990), and since then, no intensive survey has been conducted to update the information on this species. It is believed that the elephant population on Sumatra is declining very rapidly due to the habitat loss, conflicts with humans, and poaching. Most of the habitat loss is the result of massive forest conversion to the large plantations, and the transmigration program used by Indonesian government to resettle people from Java and Bali to Sumatra during the 1980's (Fearnside 1997). Logging practices also are believed to have a significant effect on elephant habitat loss in Sumatra (WWF 2003). During 1990 to 2002, Sumatra lost about 60% of its remaining forest through conversion to human settlements, and oil palm and pulpwood plantations (WWF 2003). As a result, the elephant population in Sumatra became more fragmented and vulnerable to extinction (Santiapillai and Jackson 1990).

Lampung Province is one of the important provinces for elephant conservation in southern part of Sumatra (Santiapillai and Jackson 1990). Two national parks in this province, Bukit Barisan National Park (BBSNP) and Way Kambas National Park (WKNP) had been proposed by IUCN/SSC (The World Conservation Union/ Species Survival Commission) Asian Elephant Specialist Group as priority areas for elephant conservation (Santiapillai and Jackson 1990). In the 1980's, Lampung Province was known to have 12 elephant populations within the province, with a total population estimate of about 550-900 elephants (Blouch and Haryanto 1984; Blouch and Simbolon 1985). Today the elephant population is believed to be significantly lower with only three-isolated populations (see Chapter 2). Massive habitat lost in

the province is considered to be one of the major factors causing the elephant population to decline. In fact, forest cover in Lampung Province has declined from 19.1% in 1985 to about 10.8% in 1997, which is considered to be the highest rate of forest loss in any province in Sumatra (World Bank 2001).

Information about population size and population trend in their habitat is necessary to provide recommendations for long-term conservation of the Asian elephant, especially for elephant in Sumatra (Blake and Hedges 2004). Effective conservation management requires estimates of relative population size and an understanding of population trends.

Furthermore, poaching has been known to have a large impact on elephant populations in both Africa (Douglas-Hamilton 1987, Poole and Thomsen 1989) and Asia (Sukumar 1989; Sukumar *et al.* 1998). Currently the trend of poaching of Asian elephants is believed to have increased rapidly since CITES approved the resumption of ivory trade for five African countries (CITES 2004a). This action is believed to caused illegal killing of elephants for ivory, not just for African elephants, but also for Asian elephants, because it is very difficult to distinguish the ivory from Asia and Africa (CITES 2004b). In Sumatra, poaching for Sumatran elephant also has increased during the last few years (Sitompul *et al.* 2002). However, accurate data on poaching is very difficult to obtain. Furthermore, there has been no field study in Sumatra identifying the impact of poaching on abundance and population trends. To develop effective management strategies for Sumatran elephant, a study on impact of poaching through a modeling approach is necessary.

The objective of this study was to provide information on the elephant population size in two national parks in Lampung Province, using the dung-count method. From these data and information on population demographics, I will then developed an elephant population model

and projected the population trend under three different poaching scenarios for Way Kambas National Park. For each model, I predicted age distribution, population growth rate, and abundance estimates over 50 years. Finally, I calculated the extinction probability for each scenario and conducted sensitivity analysis to identify the parameter had the largest effect on the model estimates.

METHODS

Population estimate

Estimating elephant populations in forested ecosystems using direct count methods is quite problematic. Limited visibility in the forest due to dense vegetation can hinder detecting and counting them directly forest on the ground and from the aerial surveys. Therefore, wildlife biologists developed indirect method using a dung-count technique to estimate elephant population in the forest (Barnes 1993). The fundamental concept of dung count technique is to converts elephant's dung density into elephant density (Barnes and Jensen 1987, Dawson and Dekker 1992, Barnes 1993). Elephant population estimates using dung-based surveys are believed to be more precise than aerial survey (Barnes 2001, 2002). Furthermore using dung count method, changes in elephant abundance overtime are more likely to be detected compared to the aerial survey (Barnes 2001, 2002). For the dung-based surveys, elephant abundance is estimated based on three parameters dung density, dung defecation rate, and dung decay rate (Barnes 1993).

Dung density and sampling strategy

We conducted dung-count surveys using line-transect sampling (Buckland *et al.* 2001, Laake *et al.* 1993). We used stratified random sampling to estimate dung density in BBSNP and WKNP. To estimate dung density in the park, we use Buckland's (2001) equation:

$$D = n_i / 2wL_i$$

Where;

D = dung density; n_i is total number of dung piles observed; L_i is total transect length and w is optimum reliable detection distance.

In BBSNP, two teams conducted the dung counted surveys simultaneously in the northern and southern portion while working towards to the center of the park. Surveys were conducted during May 2001 to November 2001. Sampling area was spaced uniformly at 10-km intervals from north-south by one team and south-north by other team. This survey design was applied to avoid biased estimates due to elephant movement. The starting point at each location was randomly chosen and transect orientation was placed both toward north and south compass bearings.

A second survey type called “recce” survey or reconnaissance method involved observers walking along non-straight lines in the forest and counting all dung piles found (Walsh and White 1999). Locations of “recce” transects were established at 50 meters to the east and west of a line transects. Data from this survey were used to assess whether follow-up line transect survey would be needed. Based on the result of “recce” survey method, we stratified the park based on high and low elephant dung encounter rates. We then optimized survey one each strata to get in order to get reliable estimate of dung density. The “recce” was developed by Walsh and White (1999) and has been used as an alternative survey technique for elephant abundance estimate. They found a strong relationship between dung pile encounter rates in line transect and the dung pile encounter rate in “recce” (Walsh and White 1999). Therefore, dung encounter rate in “recce” can be used to calibrate dung count in line transect in the functional relationship using linear equation as long as they conducted in pairs (Walsh and White 1999).

Three pairs of line transects (maximum 3 km each transect) were combined with a pair of “recce” transects placed at each location. In WKNP, three teams were formed to complete dung count surveys in the park during September 2001 to March 2002. Stratified sampling design was developed based on the Santiapillai and Suprahman (1986) study. Transect orientation and sampling procedure was set up in BBSNP. Finally, separate estimates of dung pile density from both parks were obtained for each stratum using the DISTANCE program. Three models for the detection function were considered: half-normal, uniform, and hazard rate. Choice of the final model was based on a combination of smallest AIC (Akaike’s Information Criterion) and a low variance (Buckland *et al.* 2001).

A dung decay rate was estimated for both parks, by monitoring dung-pile disappearance rates. In BBSNP, we developed one team to search for wild elephant’s dung on a monthly basis around Way Canguk Research Station during July 2000 to December 2002. Way Canguk Research station was located in the southern part of the BBSNP (5°39’32” S and 104°24’21”E). Each dung pile was marked and monitored daily during the first week and weekly thereafter until dung piles completely decayed. In WKNP, we used elephant’s dung from free-ranging elephant in the Elephant Conservation Center and placed them into three habitat types. Scrub, grassland, and forest habitat types were chosen to identify dung decay variability in each habitat type during June 2000 to March 2002. Similar to BBSNP, dung piles in WKNP were monitored daily during the first week and weekly thereafter until each individual dung pile was completely decayed.

Dung defecation rate was estimated from 10 free-ranging elephants in WKNP over three periods (June-August 2000, January-April 2001, and August – October 2001). Defecation data were collected after the elephants had spent a minimum period of 72 hours foraging on natural

vegetation. Once the purging period was complete, a daily monitoring routine was established. Three vegetation types were used for the diurnal feeding areas: forest (tree dominated secondary forest), mixed-scrub (regenerating areas with dense shrubs and grass patches), and swamp (sedge and grass dominated areas). Each of these areas was used for a minimum of 7 days in succession, thus the elephants used each vegetation type twice during a trial. For more detail on defecation trial methods see Tyson *et al.* (in review).

Studies on dung-count based elephant surveys in Asia and Africa mostly use the “steady stage” approach when calculating elephant density from dung-pile density, dung disappearance rates, and defecation rates. The “steady stage” approach was developed to facilitate relatively quick and computationally simple estimates of elephant population sizes from dung surveys (McClanahan 1986, Barnes and Jensen 1987). The approach was based on the fact that if defecation rate and decay rate remain constant in the system, then the density of elephants are also constant and the amount of dung produced will equal the amount that disappears once the system is in equilibrium. It can be readily shown that once the system has achieved equilibrium (achieved a “steady state”), the density of dung-piles per square kilometer will remain constant. If $\hat{E}$ is the estimated number of elephants per square kilometre then $\hat{D}$ is the estimated number of dung-piles produced per elephant per day, $\hat{Y}$ is the estimated number of dung-piles per square kilometer, and $\hat{r}$ is the estimated daily rate of dung-pile disappearance, then the elephant density can be calculated as:

$$\hat{E} = \hat{Y} * \hat{r} / \hat{D}$$

However, it was always recognized that the ‘steady stage’ approach was based on assumptions that were unlikely to apply for much of the time in most areas, particularly the assumption of a constant dung disappearance rate. Therefore alternatives to the “steady stage” approach have

been developed during the last 12 years (Hiby and Lovell 1991; Plumptre and Harris 1995; Barnes *et al.* 1997). Dung-pile density was converted to estimates of elephant density by combining data on dung-pile decay rates and defecation rates using the DUNGSURV program (Hiby and Lovell 1991). Their method relies on deriving a correction factor that relates observed dung pile to density of elephants based on the probability of dung-piles dropped prior to the survey still being visible during the survey. Following Barnes (1993) and Plumptre (2000), the variance of the final estimate $\hat{E}$ was calculated using the expression:

$$CV^2(E) = CV^2(Y) + CV^2(r) + CV^2(D),$$

where, $CV(X)$ = coefficient of variation of variable X (standard error/mean * 100%). This equation, assumes that the values of the variables are not correlated. The resulting estimates of elephant density were converted into elephant numbers using the estimates for the extent of suitable elephant habitat (forest, scrub, and grassland) in the two parks. The total areas of these vegetation types were obtained from interpretation of satellite imagery and confirmed with the ground-truth surveys.

Population model

Population trajectories and maximum population size under different scenarios were predicted for elephants in WKNP using Leslie matrix projection model (Leslie 1945, 1948). In Leslie matrix, an elephant population can be modeled in multiple age distribution. In this population model, I used an initial population vector containing four age classes, and age-specific birth rate and survival rates. I incorporate stochasticity into the model by generating a random distribution of survival rates from beta (β) distribution and I allowed the parameter to vary 10% from the mean.

I specified the age distribution into four different age classes, calf, juvenile, sub-adult, and adult elephant as defined by Sukumar (1989). The calf class included any elephant <1 year old, juvenile included ages 1-5 years, sub-adult elephant included ages 5-15 years, and adult included ages >15 years. Age specific maximum fecundity rate for the model was assumed to be constant over time and estimated to be 0.225 for both sub-adult and adult elephants. This rate was based on long-term study of Asian elephant in other regions (Sukumar 1989). Natural mortality rate was assumed to be similar to Asian elephants in India. The natural age specific mortality rate in this model was defined as 0.15 for calf, 0.04 for juveniles, 0.02 for sub-adults, and 0.15 for adults. Demographic configuration of the elephant population in WKNP was taken from Reilly's (2002) study in the park during 1997. This study investigated the age structure of elephant populations in the park, which was derived from sizes of dung encountered in the park. Result of the study showed the proportion of calf in the park was 8.04%, juveniles were 28.57%, sub-adult were 50%, and adult were 13.39% (Reilly 2002).

I conducted the simulation for 1,000 iterations and for a 50 year time period, and then observed the final population structure. Mean and 95% confidence interval (95% CI) of population size, population structure, and population growth rate (λ) were calculated. In addition an quasi-extinction coefficient (*EC*) after 1,000 simulations was determined. The extinction coefficient was defined as proportion of simulations in the model that resulted in extinction before 50 years.

Three different scenarios were considered in the simulation. The first scenario was called the control, which assumed that the elephant population in the park was fully protected, resulting in no anthropogenic removal of elephants (no poaching). The second scenario assumed poaching occurred at a low rate. This rate was defined as the mean number of elephant removed from the

population per year due to poaching between years 2000 to 2004. Number of elephant poached in the park was estimated from total carcasses found in the park, which had a sign of poaching activity on the elephant in year 2000-2002 (eight elephants) and eight elephants that had been found killed by poachers in between 2003 and 2004 (Sitompul *et al.* 2002, WCS unpub. data). I assumed only sub-adult and adult elephants were poached. In these scenarios, I modeled poaching rates as a function of population size using several different relationships. Model (1) assumed poaching occurred with constant rate overtime, model (2) assumed that poaching was a negative linear function of population size, model (3) assumed poaching was an exponential decay function of population size, and model (4) assumed poaching was a logistic function of population size. The third scenario assumed that high poaching would occur in the park based on continued human and land use trends in Lampung Province. High poaching was defined as a two-fold increase of the previously defined lower poaching level described above. For high poaching scenarios, poaching functions were kept the same as in a lower rate function. Rate of poaching per year in the model was assumed to be additive to the natural mortality and age specific.

For each model the number of sub-adult and adult elephants poached from the park was randomly assigned using a Poisson distribution and the scenarios specific rate. Since there is no information in sex ratio of the elephant population in the park and it is unreasonable to use sex ratio from other regions; therefore, I decided to exclude sex-specific factors of poaching in the model. I outlined the model structure in Figure 4.1.

Several other assumptions were required in constructing the models. Natural mortality rates used in this model were derived from data on Indian elephants, which might be different than Sumatran elephants. However, it is very unlikely that they would be significantly different

because they have similar life history. The other assumptions, which have been primarily to make the model more realistic, are that the natural mortality rate within each age classes was assigned from beta distribution with 10% variance and fecundity of breeding females. In addition, the population model did not include a carrying capacity function because the carrying capacity of the study area is not well studied, but is thought to be much higher than the present population. In addition, this model is more concerned with declining populations and extinction probability; therefore, density-dependent factors affected by approaching k were not important. The potential genetic problems associated with small, isolated elephant populations (i.e., inbreeding depression) were not included in this model.

Sensitivity analysis

The purpose of the sensitivity analysis was to determine the impact of a given parameter used on the model estimates (Williams *et al.* 2001). Relative change in the model can be observed by varying model input parameters over identified range. As a result, we can determine the input parameters in the model that result in significant changes to the final output of the model. Therefore, it is fundamental to construct sensitivity analysis to give us better understanding of the process within the population model. For this study, I identified the sensitivity of reproductive parameters between sub-adult and adult elephants. I set the range of the reproductive parameter from 0.19 to 0.25, with 0.01 increments. I also determined the sensitivity of survival rate parameter of calf to juvenile and sub-adult to adult. For survival rate, I set the range of survival parameter from 0.75 to 0.90, with 0.05 increments.

To understand the sensitivity of the model to the poaching function, I specified the variability range of poaching rate from 50% to 200% of the estimate values with 10% increment. To evaluate the sensitivity of each parameter I used the method described by Wiegand *et al.*

(1998). Sensitivity of each parameter was identified, by examining the Sensitivity Index (SI) of the model. Sensitivity Index of each parameter can be calculated by multiplying slope and uncertainty of the parameter. For poaching sensitivity analysis, I only used low poaching scenarios for the analysis. The result of sensitivity analysis for high poaching scenarios would be identical with low poaching since the difference between low and high poaching scenarios would be simply the magnitude of the poaching rate. Finally, I use macro language program from SAS (SAS version 8.2) to determine the sensitivity of each parameter in the model. I used regression analysis to calculate the slope and uncertainty of each poaching functions.

RESULTS

Population estimate

In BBSNP, a total of 1,313 elephant dung-piles was observed along 58 transects with a total length 73.63 km. Point estimates for dung pile density were 3,186.7 and 156.0 piles per square kilometer in the high and low-density strata respectively. The mean defecation rate derived from the other studies of free-ranging elephants in WKNP was 18.15- defecation per 24-hour (13.94% CV) (Tyson *et al.* in review). The disappearance rate of 1,302 dung-piles was monitored over the July 2000 – November 2001 period in BBSNP. The DUNGSURV program provided an estimate of dung pile duration of 305.36 days (2.4% CV). Elephant density was estimated to be 0.57 elephants/km² (15.39% CV) in high-density stratum and 0.03 elephants/km² in the low-density stratum (14.59% CV). Area-weighted mean density of elephants in BBSNP was 0.185 elephants/km², giving an estimated population of 498 (373-666, 95% CI) elephants in BBSNP during 2001 (Tables 4.1 & 4.2).

In WKNP, a total of 1,093 dung piles was observed along 80 transects with a total length 212.31 km. Point estimates for dung pile density were 1,012.75 and 221.54 piles/km², in the

high and low-density strata, respectively. Analysis of these data using the DUNGSURV program yielded equivalent dung-pile duration of 459.84 days (1.3% CV) in the low-density stratum (grassland and scrub) and 231.5 days (1.9% CV) in the high-density stratum (secondary forest). Using the same dung defecation rate as used for BBSNP and dung decay rate that was observed in WKNP ($n=4,881$ dung piles), I obtained point estimates of 0.24 elephants/km² (10.40% CV) and 0.03 elephants/km² (20.04% CV) in the high and low density strata, respectively. These data yield an area-weighted estimate of 180 elephants/km² (144-225, 95% CI) WKNP in 2001 (Tables 4.3 & 4.4).

Population model

Projection of the elephant population over the 50-year period in WKNP showed the population increasing from 180 elephants to 594 elephants (570-618, 95% CI) if we assume poaching can be stopped. Extinction coefficient for the control population was 0 and population growth rate (λ) was 1.02 (0.0001 SE). The low poaching scenarios also showed that the elephant populations would increase in the park (Fig 4.2). Linear poaching function produced an elephant population in year 50 of 422 (403-441, 95% CI). Extinction coefficient using the linear function was also 0 and λ was 1.02 (0.0002 SE). If poaching in the park behaves as an exponential extinction function, the elephant population in year 50 was estimated to be 325 (308-342, 95% CI). Extinction coefficient for this function was 0.009 and λ was 1.01 (0.0002, SE). Constant and logistic poaching function in the model produced estimates of elephant population size at 253 (235-271, 95% CI) and 263 (245-281, 95% CI), respectively. Extinction coefficient with constant poaching was 0.099 and logistic poaching was 0.086. Population growth rate with constant poaching was 1.0 (0.0005, SE), and λ with logistic poaching was 1.0 (0.0005, SE) (Table 4.5). Age distribution after 50 years in the population for control and low poaching

scenarios changed slightly from being dominated by sub-adults towards becoming more dominated by adults (Fig. 4.3).

The population model with high poaching scenarios showed a different trend compared to the low poaching scenarios during the 50-year period. In high poaching scenarios, only linear and exponential decay poaching patterns showed that elephant population in WKNP would increase during 50 years (Fig 4.4). Population size in year 50 for linear and exponential decay poaching functions was estimated to be 274 (263-285, 95% CI) and 217 (211-226, 95% CI), respectively. Extinction coefficient in linear and exponential poaching functions was 0.0 and λ was 1.0 (0.0002, SE). In the exponential decay poaching function, extinction coefficient was 0.01 and λ was 1.0 (0.0003, SE). In contrast, constant poaching and logistic poaching function in the high poaching scenarios showed that elephant population in WKNP would decline dramatically (Fig 4.4). Final population size in year 50 in constant and logistic poaching function was 41 (33-49, 95% CI) and 37 (30-44, 95% CI), respectively. Extinction coefficient in constant poaching was 0.75 and logistic poaching was 0.76. Population growth rate was 0.97 (0.008, SE) for constant poaching and 0.97 (0.009, SE) for logistic poaching (Table 4.5). Age distribution in high poaching scenarios showed similar patterns to the low poaching scenarios, with more adult individuals found at the end of each simulation (Fig 4.5).

Sensitivity analysis

Sensitivity analysis for each natural parameter revealed quite high levels of variation in the model. The result of sensitivity analysis of sub-adult and adult reproductive parameter to the model showed that small change in adult reproductive parameter caused high variation in the final population size. An increase of 6% in the adult reproduction rate could cause a 76.01% change in the population size. In contrast, a 6% change in sub-adult reproduction rate only

caused 26.84% change in the final population size (Fig 4.6). In the survival parameter, sensitivity analysis showed that juvenile survival and young survival had relatively similar sensitivity to the final population size. An increase of 5% in survival of young and juvenile elephants independently caused a change of 29.25% and 29.87% final population size respectively (Fig 4.7). However, adult survival parameter was far more sensitive effect to the final population size compared to sub adult survival parameter. Changing the adult survival parameter 5% could cause an 86.54% change in the final population size. In contrast, 5% change in sub adult parameter only caused a 37.46% change in final population size.

Sensitivity analysis for the four poaching functions parameter showed clear differences in model sensitivity (Fig 4.9, Table 4.6). The logistic poaching function appeared to have the highest sensitivity, which is shown, by having the lowest index ($SI = -2.626$) followed by constant poaching ($SI = -0.013$). Linear, constant and exponential poaching functions appeared to have relatively similar sensitivity in the model (Fig 4.9). Level of uncertainty of poaching parameter in the model showed that the exponential model have the lowest uncertainty compared to the other three poaching parameters (Table 4.6).

DISCUSSION

Population estimate

The population estimate of 498 elephants (373-666, 95% CI) in BBSNP and 180 elephants (144-225, 95% CI) in WKNP revealed populations were much larger than had, in many cases, been previously reported for these parks. A UNDP/FAO report suggested that there were only about 30 elephants in WKNP (UNDP/FAO, 1979), while Blouch and Haryanto (1984) reported estimates of about 200 and 50–100 elephants for BBSNP and WKNP, respectively. Population estimates provide by Blouch and Haryanto (1984) relied primarily on interviews and

very brief field trips, and they acknowledged that their estimates were effectively “informed guesses”. On the other hand, Santiapillai and Suprahman (1986) suggested that there were 260 – 350 elephants in WKNP in 1986. Compared to the previous population estimate, it appears that the elephant population in BBSNP might be increasing while it might be declining in WKNP. It is very difficult to explain what has happened to the elephant population in both parks during the last 20 years. For certain, we do not know what was happened to the elephant population because the methods used to derive population estimates in 1986 were different than this study. However we know for certain that the differences in the population estimates are more likely because of the differences between survey methods rather than an increase in the elephant population over time. Santiapillai and Suprahman (1986) derived their estimate for WKNP from elephant densities in Sri Lanka and West Malaysia. These reported densities were themselves based on extrapolations, not sample-based survey methods. The elephant population estimate in this study was also quite different than Reilly’s (2002) estimate. Reilly (2002) estimate for the elephant population in WKNP was 569 (517-630, 95% CI) in 1994, and 561 (416-662, 95% CI) in 1997. The great difference in population size from this study compared to the Reilly’s (2002) estimate is more likely because of differences in data analysis. Fundamental differences between these studies include: (1) Dung decay rate during Reilly’s (2002) study is considered to be unrepresentative due to the small sample size. Furthermore, she used only scrubby grassland as habitat type for her dung decay trial. (2) Defecation rate during her study (1994 and 1997) were quite likely to be affected by an unusual dry season -El Niño Southern Oscillation (ENSO)- in Lampung. It is suspected that elephant defecation rate was much lower during ENSO (Tyson *et al.* in review). Lower defecation rate could lead to overestimate elephant density in the WKNP. (3) Dung decay rate was estimated using the faulty “steady stage” assumption. (4) No

stratification based on habitat type was used in the survey. Each habitat type in the park was assumed to have equal elephant density. This false assumption could lead over estimate elephant density in the park.

Regarding to the lack of reliable population estimate in the past, it's difficult to make exact comparison of the elephant population in WKNP over time. However, there is a possibility that the elephant populations in BBSNP and WKNP are declining due to the conflict with human and poaching. Loss of significant amounts of habitat in both parks also was suspected to be the major caused of the elephant population decline. Recent studies on the deforestation BBSNP by Kinnaird *et al.* (2002) showed that at least 661 km² of the forest disappeared inside the park and 318 km² were lost in a 10-km buffer around BBSNP. In WKNP, encroachment has occurred in about 10 % of the park by at least 500 families in the last five years (Head of WKNP, pers. comm). Due to the habitat destruction, elephants in these parks are more exposed to humans and as a result elephants are killed because of poaching or captured. Poachers in BBSNP killed at least 23 elephants, and nine elephants were found killed in a period during January 2000 to November 2002 and in WKNP (Sitompul *et al.* 2002).

Population model

The elephant population model clearly demonstrates that in “control” scenarios the elephant population in the park will increase over time. Low poaching scenarios, interestingly show elephant populations also increase. These results imply that poaching activities that occurred in the last 5 years did not have negative impact to the elephant population in the park. Population growth rate in the low poaching scenarios remained about 1.0 or above and extinction encounter after 1,000 simulations was less than 0.1. If the poaching doubled from the current rate as defined in the high poaching scenarios in this study, then we found that the population

could decline dramatically in logistic poaching function and constant poaching function.

Extinction coefficients for both poaching functions increased significantly up to about 75%.

From this result we could conclude that there is a relatively high chance of the population going extinct in 50 years. In both, constant and logistic poaching function, the magnitude of poaching rate pushed the population down beyond the limit for the population to grow. In contrast, linear poaching function and exponential poaching function did not differ much from the lower poaching scenarios. In this situation, poaching (linear and exponential functions) seemed to have little effect on the population even though the magnitude of the poaching increased two fold from the low poaching scenarios. The reason this situation occurred is most likely because of poaching followed the fluctuation of population size and negated the effect of poaching on the population, so the overall effect of poaching is very small.

Age distribution in the model showed that the proportion of age classes in the population shifted towards the adult age classes for low and high poaching scenarios. The overall pattern of age distribution for both poaching scenarios was the same, where the highest proportion of the population dominated by the adult and followed by calf, juvenile and sub adult. If we examine the relationship between population growth and age structure after the simulation in the model, we found that in low poaching scenarios the population is predicted to grow after 50 years. A similar pattern also was found in the exponential and linear poaching functions in the high poaching scenario. If the population is growing, that means the population growth rate is equal or more than one. In this situation we expect the age distribution at the end of simulation year to be predominated by the younger age classes than older age classes. However, the result of this population model did not conform to that theory. The reason this situation happened may be because the reproduction rate was kept constant and the survival rate at each classes was

randomized. As a result there was not enough new recruitment that could shift the age distribution towards the younger age classes.

Sensitivity analysis

Sensitivity analysis showed that variation in reproduction parameters for adults had the greatest impact on model variability. Relatively small changes in adult reproduction rate could cause a significant impact on the population. Therefore, reproduction rate of adult elephants need to be determined accurately. Other than to determine the population trend, reproduction rate in the population is also an important aspect to identify the demographic condition of the population. If we assume reproduction rate in the population to be deterministic, and compare the sensitivity of the survival rate, we found the model was more sensitive to adult survival parameter compared to sub adult survival parameter. Sukumar (1989) suggested that among adult elephants, the adult female had a more significant effect on the population compared to the adult male. His study suggested that if adult male elephants have low survival, the population could still grow if female survival rate still high. Similar results have also been demonstrated for other long-lived species such as grizzly bear in Yellowstone National Park (Eberhardt et al. 1994).

Sensitivity analysis in poaching parameter revealed that there was a clear sensitivity pattern in poaching function in the model. The sensitivity of the poaching function was reflected from sensitivity index value of the parameter. Sensitivity analysis showed logistic poaching function was the most sensitive poaching function. Highest sensitivity in logistic poaching was the most likely because of the number of elephants poached per year was maintained in the maximum level and at the same time there was a randomization incorporated in the function. Clear differences can be found if we compare to the sensitivity of logistic function with constant

poaching function. In constant poaching function, even though number of elephant poached per year maintained in the maximum level, but since there was no randomization incorporated in this poaching function this model, so it tended to be less sensitive.

MANAGEMENT IMPLICATIONS

Information on elephant population size in WKNP and BBSNP from this study is very important and fundamental for the management of Sumatran elephant, especially in Lampung province. This population estimate is the first to be based on rigorous scientific methods. Furthermore, population estimates from this study can be use as base line data for monitoring the population over time. It is clear that population monitoring in both parks is necessary to develop appropriate management for the species. A 5-year monitoring program is reliable period of time for establishing management strategies for the elephant population in WKNP. Monitoring should not just focus on population size, but also should assess population structure, and sex ratios. Previous studies showed that elephant population structure can be determined from dung dimension (Reilly 2002) and sex ratio can be derived from fecal DNA (Eggert *et al.* 2003). Information about population structure and sex ratio is very important information in order to build a population model as a part of an adaptive management strategy.

Based on this study, natural parameters, such as adult reproduction and survival, are considered to be a key parameter to the population model. Therefore, accurate information on this parameter is very important for setting up management strategies for the population. It also is important to accurately determine poaching rate. Sukumar (1998) emphasized that poaching activities for Asian elephant could result in extremely skewed sex ratios of the population. Therefore, reliable data on poaching or other elephant removal is very important for management.

The elephant population model in this study was constructed based on the last 5-year poaching data in WKNP. The model indicates that the elephant population will not decline for the next 50 years. Whereas this result is encouraging, there is possibility that poaching data used in this study actually underestimate the real poaching activities in the park because it was based on number of elephant remains actually found without dedicated carcass searches. There is a possibility that the number of elephant killed because of poaching is higher than this estimate. Therefore, accurate poaching assessment (eg. systematic carcasses searching) should be set up as priority for management. Combining elephant population estimates and poaching monitoring is very important to determine what type of poaching function is regulating the elephant population size. If it turns out to be a logistic function, then immediate action to stop poaching should be established as a priority for the management. Finally, this model did not incorporate habitat changes or destruction in and around the parks. It is well documented that poaching or illegal killing of elephant is correlated with habitat destruction and human-elephant conflicts around the park in Sumatra (Hedges *et al.* in review; Sitompul *et al.* 2002). Therefore, elephant population management in both parks should also focus on mitigating habitat destruction and human elephant conflict around elephant habitat.

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Table 4.1. Dung density estimate in high and low-density stratum in Bukit Barisan Selatan National Park using line transect dung count survey during May to November 2001.

Stratum	Number of transects	Total length of transects (km)	Number of dung piles	Dung density/ km²	95% CI	CV
High density	40	50.43	1283	3186.765	2224.184 – 4149.346	15.41%
Low density	18	23.20	30	156.041	20.578 – 291.505	41.14%

Table 4.2. Elephant population density and total population estimate using dung count method in Bukit Barisan Selatan National Park in 2001.

Stratum	Area of elephant habitat (km²)	Elephant density (per km²)	Estimated number of elephants	95% CI	CV
High density	773	0.573	443	325 – 603	20.92%
Low density	1938	0.029	55	48 – 63	43.5%
Total			498	373 - 666	

Table 4.3. Dung density estimate in high and low-density stratum in Way Kambas National Park using line transect dung count survey during September 2001 to March 2002.

Stratum	Number of transects	Total length of transects (km)	Number of dung piles	Dung density/ km²	95% CI	CV
High density	56	164.428	991	1012.749	803.943–1221.555	10.52%
Low density	24	65.883	102	221.537	121.754–321.320	21.77%

Table 4.4. Elephant population density and total population estimate using dung count method in Way Kambas National Park 2002.

Stratum	Area of elephant habitat (km²)	Elephant density (per km²)	Estimated number of elephants	95% CI	CV
High density	694	0.239	166	135-204	10.40%
Low density	541	0.026	14	9-21	20.04%
Total			180	144-225	

Table 4.5. Summary of model result representing final population size; population growth rate and extinction encounter using all possible scenarios in the model. f = poaching function of population size. N_{50} = population at year 50; λ = population growth ate; EC= Extinction Coefficient.

Scenarios	f	N_{50}	95%CL	λ	95%CL	EC
Control		594	23.59	1.02	0.0002	0
Low-poaching	Constant	253	17.87	1.01	0.001	0.099
	Linear	422	19.03	1.02	0.0004	0
	Exponential	325	16.63	1.01	0.0006	0.009
	Logistic	263	17.80	1.00	0.0009	0.086
High-poaching	Constant	41	7.86	0.97	0.016	0.75
	Linear	274	11.08	1.00	0.0005	0
	Exponential	217	9.40	1.00	0.0007	0.01
	Logistic	37	7.09	0.97	0.018	0.76

Table 4.6. Sensitivity analysis of the poaching parameter. Poaching was specified as function of population size. β_0 = parameter value; $\alpha(\beta, \beta_0)$ = slope ; $\Delta(\beta)$ = approximate uncertainty in the parameter; $SI(\beta, \beta_0)$ =sensitivity index of parameter β within point β_0 .

Poaching	β_0	$\alpha(\beta, \beta_0)$	$\Delta(\beta)$	$SI(\beta, \beta_0)$
Constant	2.848	-0.258	0.049	-0.013
Exponential	2.630	-0.105	0.012	-0.001
Linear	2.780	-0.161	0.000	0.000
Logistic	4.050	-1.802	1.457	-2.626

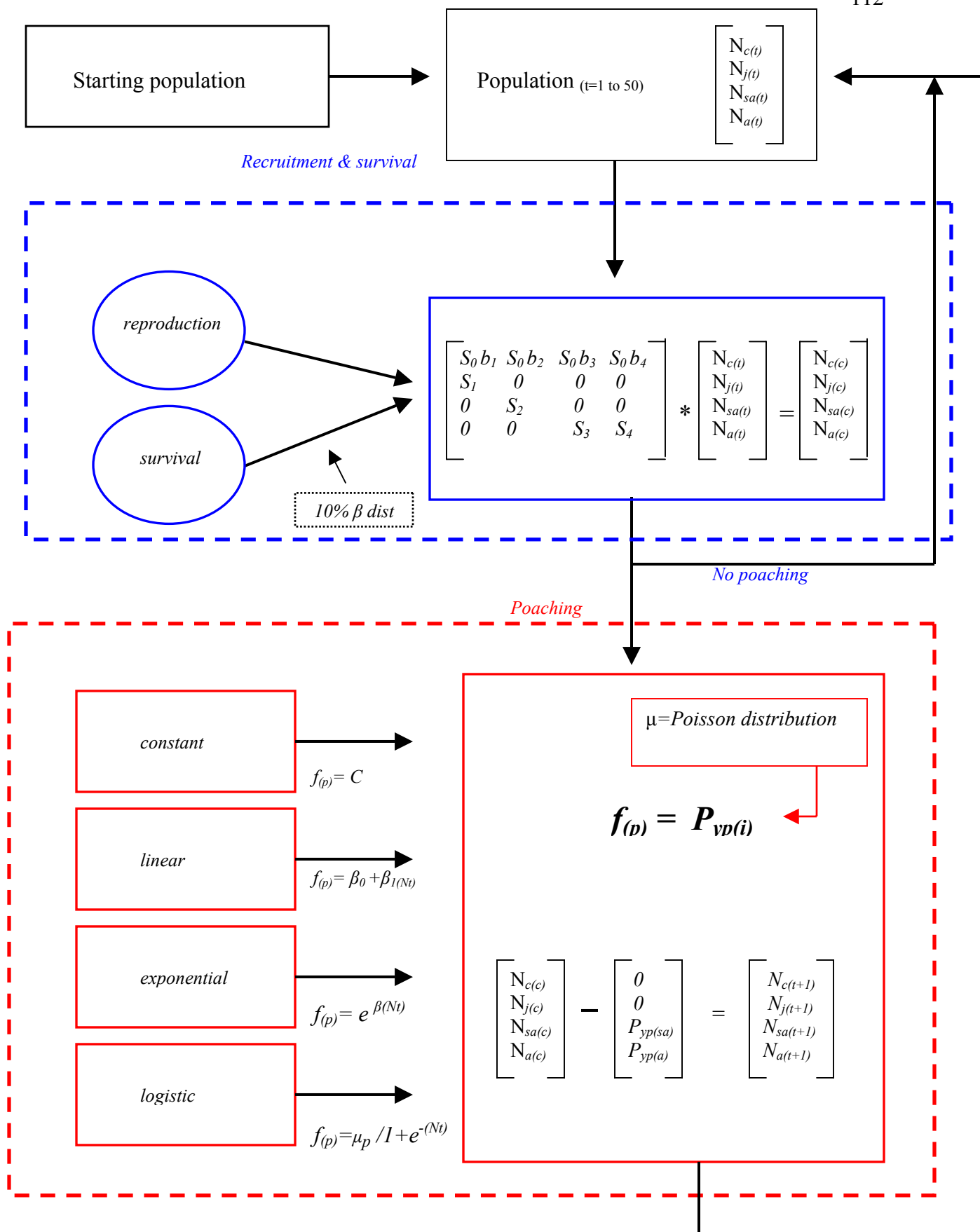


Fig 4.1. Model flow for population estimation and demographics as a function of recruitment, survival and poaching projected for 50 years in Way Kambas National Park.

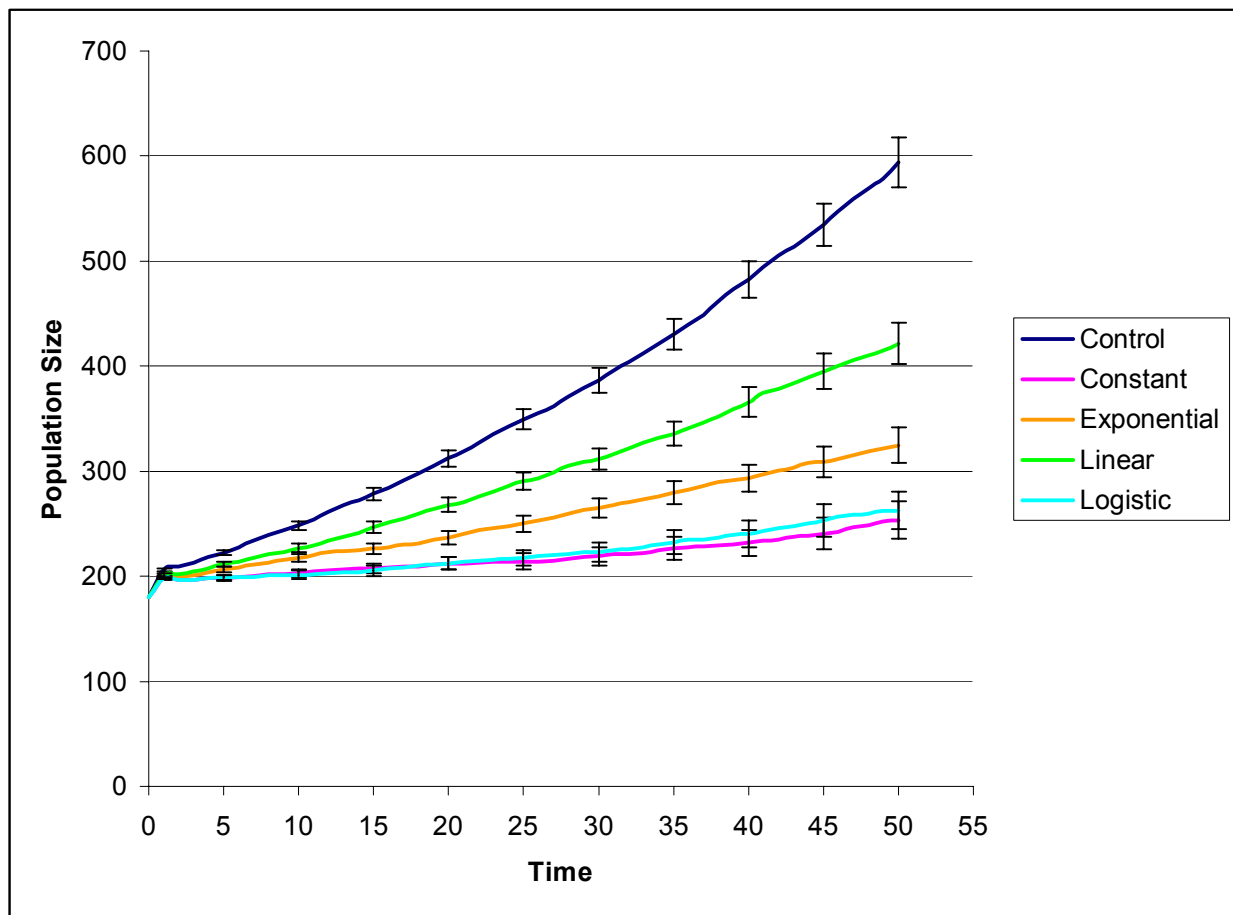


Figure 4.2. Simulated population trends over 50 years period under control and low poaching scenarios in Way Kambas National Park. Density dependent effects using low poaching level scenarios were developed (constant, exponential, linear and logistic).

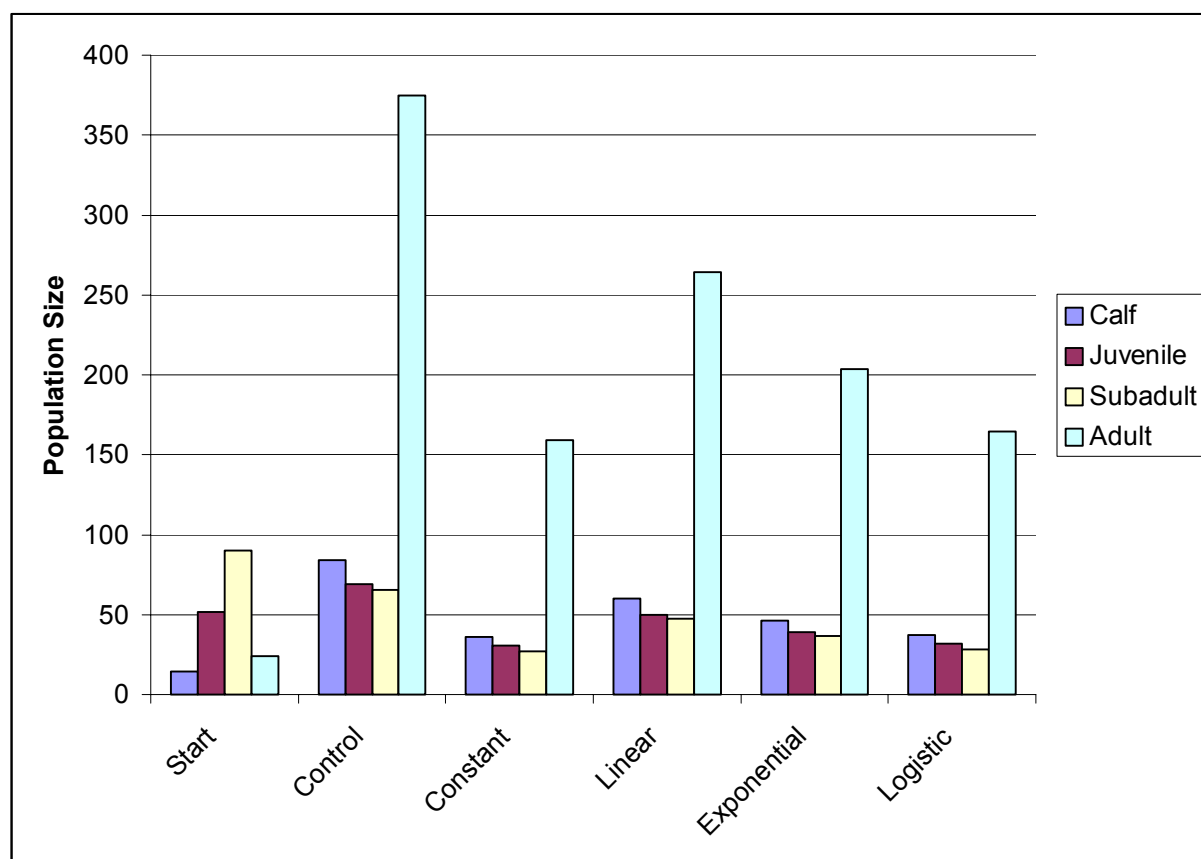


Figure 4.3. Projection of the age structure of the elephant population in Way Kambas National Park after 50 years of simulation, presented in the current population (start) and in control and low poaching scenarios.

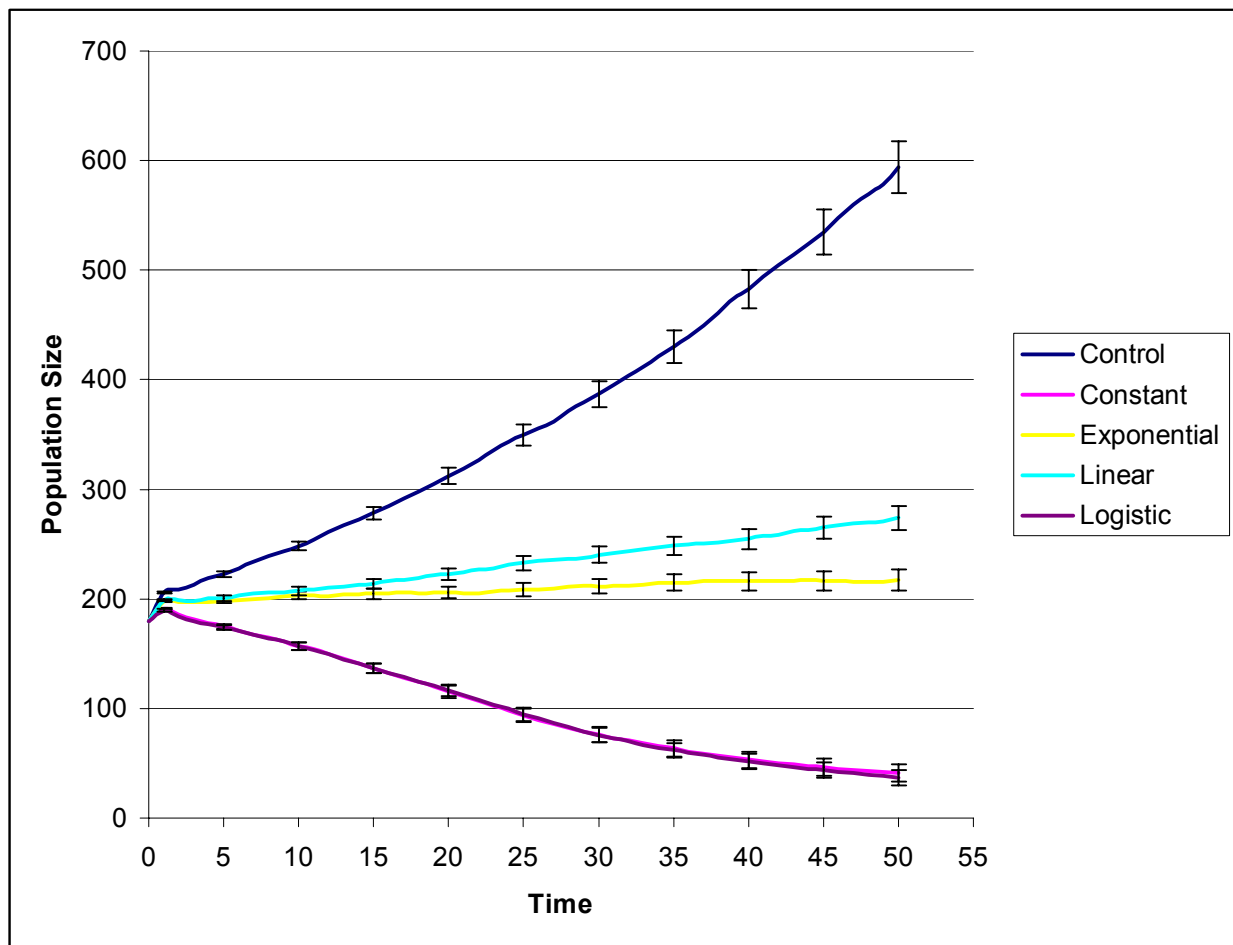


Figure 4.4. Simulated population trends over 50 years period under control and high poaching scenarios in Way Kambas National Park. Density dependent effects using high poaching level scenarios were developed (constant, exponential, linear and logistic).

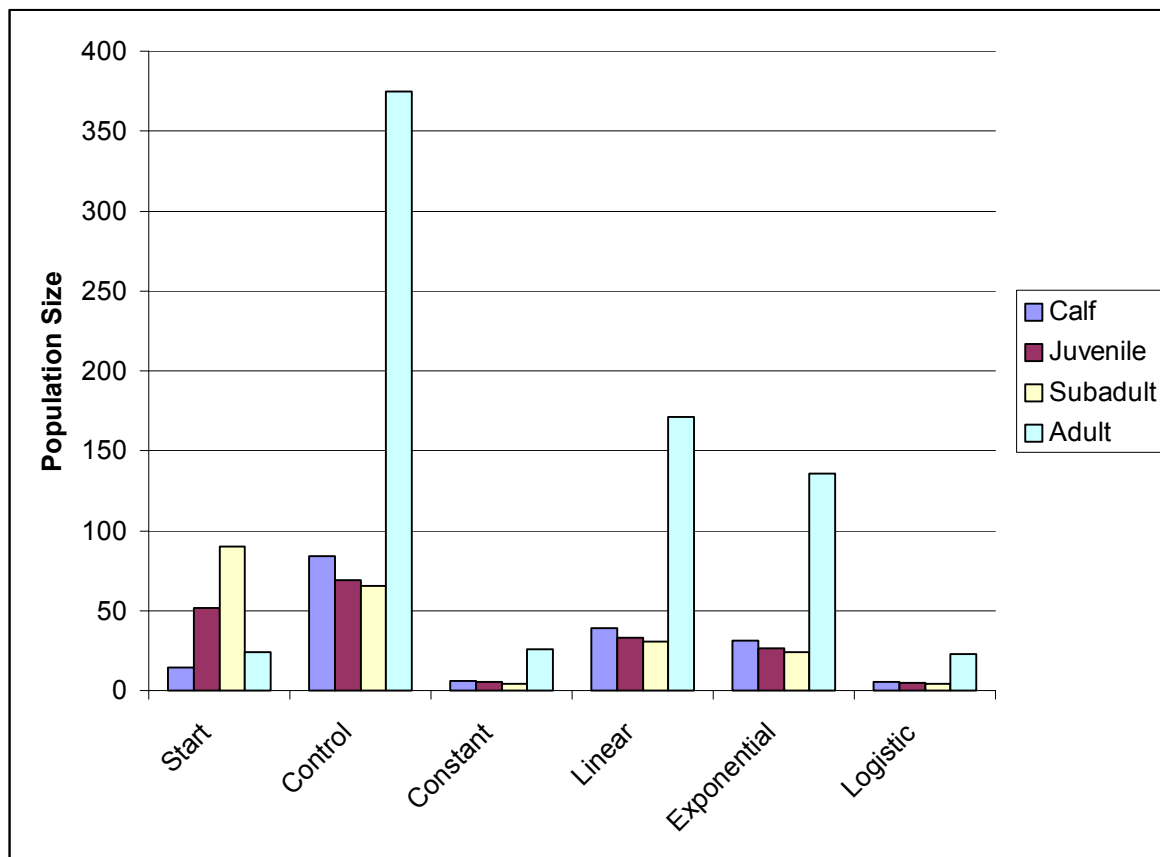


Figure 4.5. Projection of the age structure of the elephant population in Way Kambas after 50 years of simulation, presented in the current population (start) and in control and high poaching scenarios.

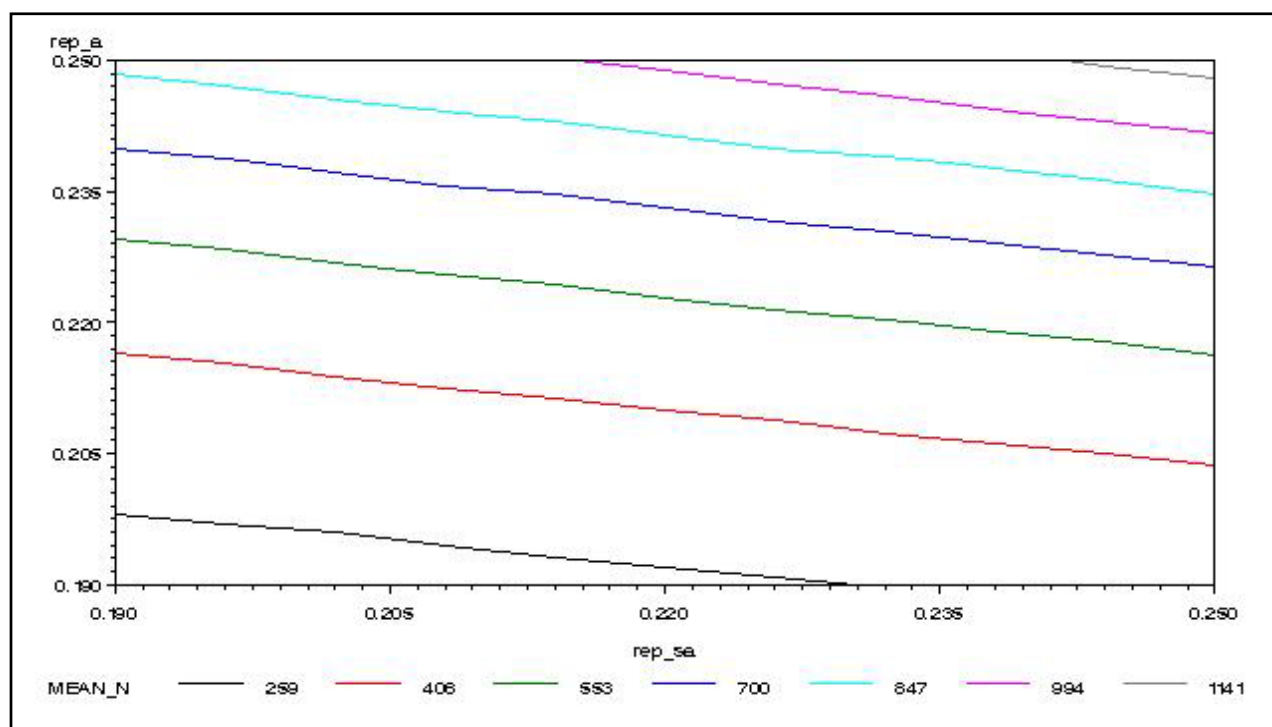


Fig 4.6. Response on predicted elephant population size in 50 years simulation for various combinations of adult reproduction rate (y-axis) and sub adult reproduction rate (x-axis). Lines of different colors represent elephant population size for specific adult and sub adult reproduction rate.

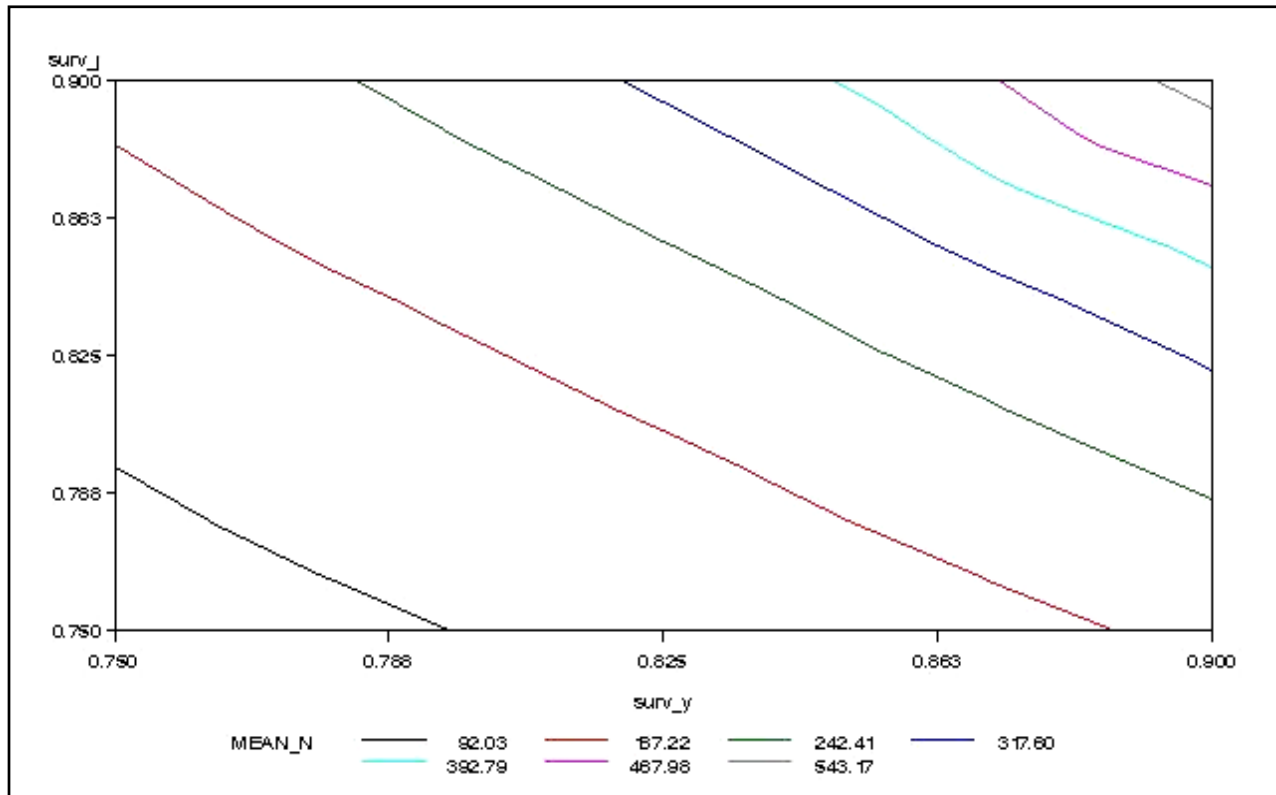


Fig 4.7. Response on predicted elephant population size in 50 years simulation for various combinations of juvenile survival rate (y-axis) and calf survival rate (x-axis). Line of different colors represents elephant population size for specific juvenile and calf survival rate.

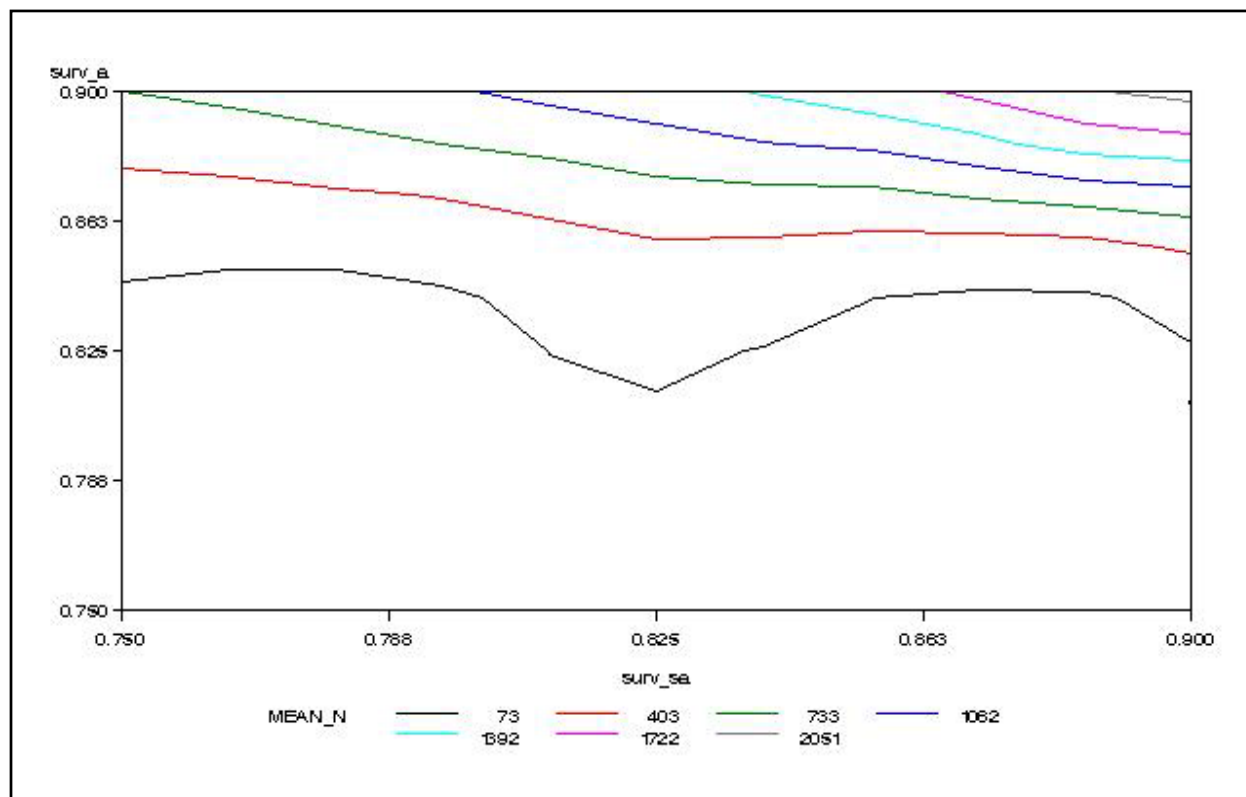


Fig 4.8. Response on predicted elephant population size in 50 years simulation for various combinations of adult survival rate (y-axis) and sub adult survival rate (x-axis). Line in different color represents elephant population size for specific adult and sub adult survival.

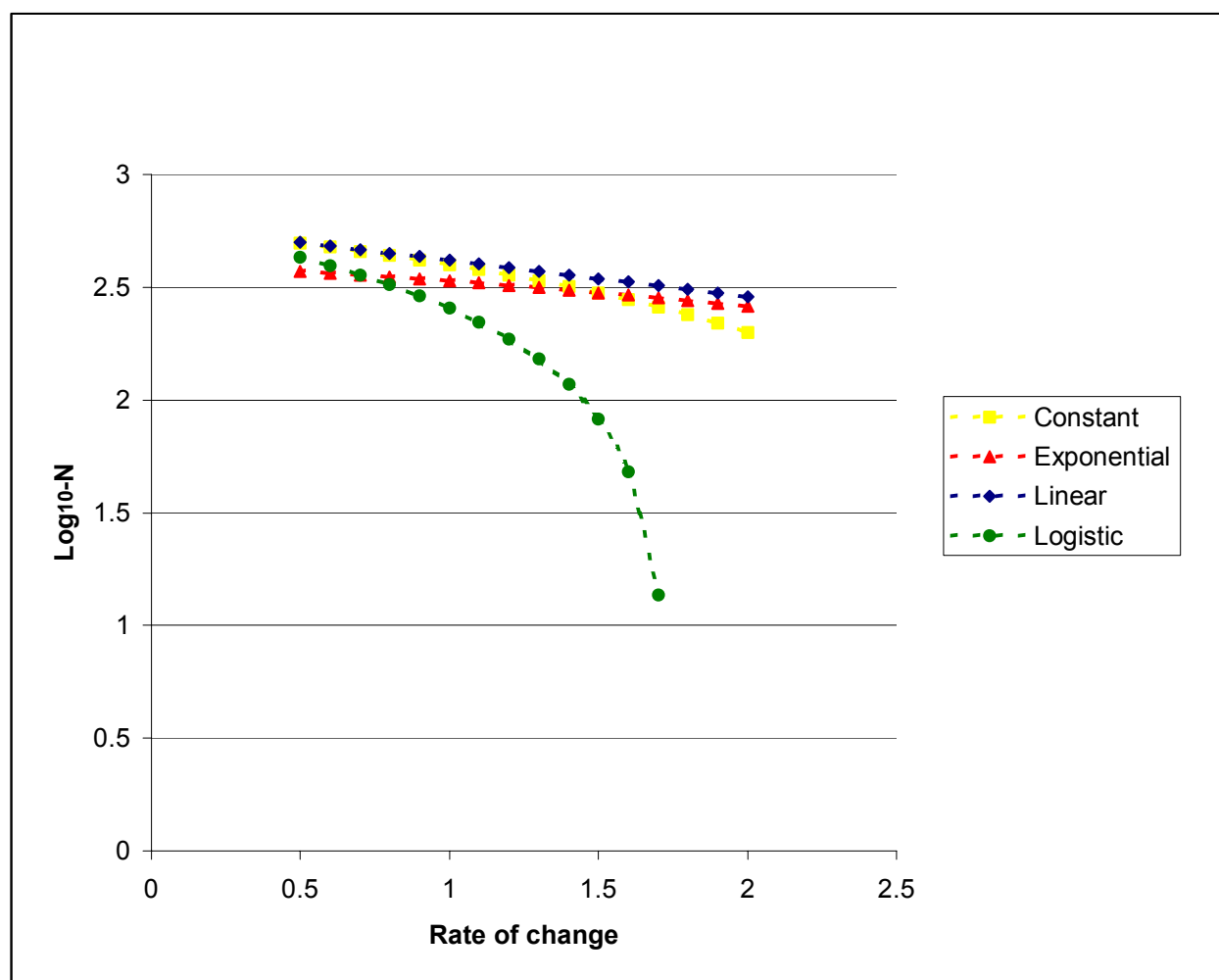


Fig 4.9. Response of the elephant population size in 50 years simulation to the rate of change on the poaching function parameter performed in the model. Different color line represents different poaching function in the model.

CHAPTER 5

CONCLUSIONS

Pattern of crop raiding

Crop raiding is the major form of human-elephant conflict around Bukit Barisan Selatan (BBSNP) and Way Kambas National Parks (WKNP) in Sumatra. Even though the total number of incidents between the two parks was quite similar, monthly incidents between the two parks were relatively different. Crop raiding locations in BBSNP were more clustered compared to WKNP. Spatially, crop raiding in BBSNP occurred more frequently at more than 3 km from the park boundary. In contrast, spatial distribution of crop raiding at WKNP was much closer (<1 km) from the park boundary.

Temporal patterns of crop raiding in both parks showed that there was no correlation of frequency of crop raiding incidents with rainfall pattern. Furthermore, frequency of crop raiding in WKNP was not significantly different in dry and wet seasons. However, higher frequency of incidents occurred in the agricultural area near the river during dry seasons. In contrast to the rainfall, crop raiding in WKNP was strongly correlated with the harvest seasons of some crop types. Frequency of crop raiding was strongly correlated with rice harvest period, particularly one month before rice harvest. Crop raiding was negatively correlated during the maize harvest period.

Thirty-one species of crops were identified as damaged by elephants around BBSNP and WKNP. Most of the crops were consumed, except a few species like chilies, pepper, and coffee, which were mainly damaged by trampling. The major crops damaged by elephants in BBSNP

and WKNP were rice, maize, cassava and bananas. The development stage of the crop during the raiding incidents was mainly either mature or ready for harvest.

Mixed group was the main type of elephant group that was responsible for most of the crop raiding incidents in WKNP and BBSNP. This pattern was different compared to the other regions in Asia and probably occurred because the population structure in both parks was different than in other regions. Furthermore, crop raiding in BBSNP is more likely affected by the seasonal movement of elephants.

Economic loss of crop raiding

Total value of the losses in 20 villages between June 2000 and May 2002 was estimated at \$12,144 US (Rp. 8,700/USD) and maximum loss per one village was estimated at \$2,091. USD. The direct economic loss of crop raiding in WKNP is considered to be relatively small regionally; however economic loss per individual farmer was significant. Since the economic loss is relatively small on a regional scale, a compensation program might be a sufficient alternative method to improve farmer tolerance toward elephants. A compensation program will most likely be a success if it is set up as a self-sustained insurance scheme and integrated with the conservation guidelines of the park.

Crop raiding severity

Model selection suggested the best approximating model obtained from the combined data from both parks was that crop damage severity was linearly related to the distance of crop raiding from the park. Additionally, there was an interaction effect showing that park together with the distance from the park influenced the level of severity of crop damage. If data from each park were treated separately, the best model and estimates of the model average effect show different results. For crop damage in WKNP, the best approximating model was a combination

of number of elephants and distance of crop raiding from the park. In BBSNP, the best approximation model was explained by only the distance parameter. Our parameter estimate showed a strong positive effect due to the park's parameter, interaction between park and elephant density, number of elephants involved in the raiding, and distance of crop field to the park boundary. Negative effects on crop damage severity were found in the slope and group type parameter.

Impact of forest loss to the elephant conservation in Lampung

Lampung province lost nine of 12 elephant populations during 1984 to 2002. The remaining elephant population is at great risk of extinction. The major cause of decline of the Sumatran elephant in Lampung Province has been habitat loss. The second largest contributor to the decline is from human-elephant conflicts. These two factors are correlated and the latter is usually a function of the former. Habitat restoration is needed to create a buffer between elephant habitat and human settlements. The possibility of improving elephant habitat quality by planting their natural food also needs to be investigated as an alternative for human-elephant conflict mitigation.

Elephant population estimate in BBSNP and WKNP

Elephant population estimates in BBSNP and WKNP based on the dung-count method showed 498 (373-666, 95% CI) elephants in BBSNP compared to 180 (144-225, 95% CI) in WKNP. It is difficult to compare the results of this study with other studies because of fundamental differences in methodology. The elephant populations in both parks are still considered viable and are recognized as core strongholds for elephant populations in Sumatra. Elephant population surveys using standardize methodology across the island is urgently needed to determine the remaining elephant population.

Elephant population modelling

Population modelling for WKNP's elephants shows that if the mean number of elephants killed from poaching over the last 5 years is correct, then the elephant population in the park will continue to grow. This result is very encouraging, however it should be realized that the poaching data from the last 5 years might not be complete. More systematic data collection to determine levels of poaching activities (such as carcasses searching) is needed to verify the model. If the poaching rate doubled from the last 5 years and poaching activities behaves as a logistic function of the population size or remains constant over time then there is a 75% chance of the population going extinct in less than 50 years.

Implications

Human-elephant conflict is considered to be the major conservation problem for Sumatran elephant in Lampung Province. Habitat loss is a major factor that leads to conflicts between humans and elephants around the remaining habitat for elephants. Despite high pressure from conflict with humans and poaching, the elephant population size is still considered to be important regionally. Without effective protection, elephant populations in these parks are threatened with extinction. In this thesis, I demonstrated the conflicts, short-term habitat threats, and model-based long-term prognosis. Immediate and effective action is needed to protect the park from illegal logging, encroachment, and poaching. Furthermore, population monitoring and mitigating human-elephant conflicts should be put as a high priority for the park management.