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Crop Raiding by Elephants Adjacent to Two National Parks in Lampung Province, Sumatra, Indonesia

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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 elephant distribution has caused a dramatic decline in the population (Thouless 1994; Hoare 1999; Zhang & Wang 2003). Extensive forest conversion to agriculture 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 conflict between them is unavoidable. One of the important issues that arise in human-elephant conflict "discussions" by the Asian and African Elephant Specialist Group in IUCN (World Conservation Union) is inadequate government policies to specifically address the problem (Dublin *et al*. 2006). Furthermore, even if the overall impact of human elephant conflict is relatively low; its effect can be significant to individual farmers (Naughton *et al*. 1998). As a result, rural communities have negative attitudes towards elephants (de Boer & Baquete 1998).

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 elephant populations in Sumatra (Soehartono *et al*. 2007). However, human-elephant conflict in and around these two parks is a serious problem, but the exact issues and mechanisms are relatively unknown. In this study, we document the level of human-elephant conflicts in BBSNP and WKNP. We used a combination of spatial data and using Information Theoretic Approach to determine causal factors to the crop damage severity in each of the parks separately and combined.

Methods

Study area

The study was conducted in BBSNP and WKNP in Lampung Province, Sumatra, Indonesia. BBSNP, Sumatra's third largest park (3568 km^2), is located in southwestern Sumatra (4^{o}31'- 5^{o}57'S; 103^{o}34'-104^{o}43' E). Altitude ranges from 0 m to 1893 m. Annual rainfall is 3400 - 4200 mm. The vegetation at BBSNP includes lowland and mountain tropical rainforest. BBSNP's elephant population is estimated at ~498 (95% CI=[373-666]) (Hedges *et al*. 2005).

WKNP (1235 km^2) is in the eastern part of Sumatra's Lampung Province (Sumatra (4^{o}62'-5^{o}26' S; 105^{o}54'-105^{o}90' E) and it dominant vegetation consists of tropical lowland and swamp forest. Most of WKNP is below 50 m. Annual rainfall is 2000 - 3000 mm per year and agricultural is mostly annual crops. WKNP's elephant population was estimated at ~180 (95% CI=[144-225]) (Hedges *et al*. 2005).

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 raiding incidents by elephant in every village around BBSNP and WKNP. Three teams (two in BBSNP; one in WKNP) visited the villages around the park monthly and measured the damage from any incidents reported by farmers. Data collection was conducted using direct measurement and an interview survey. Following Naughton-Treves (1998) we defined independent crop damage events as a single foray occasion, when an elephant crossed the park’s boundary, entered adjacent farmland, and damaged crops.

Date and time of incidents, herd size and composition were recorded for each incident collected from farmers. We also recorded number of fields damaged by elephants, type of damage (eaten or trampled), crop type and stage of crop (immature, mature, ready for harvest). Location of crop damage incidents was determined using Global Positioning System (GPS) and then imported into an Arc View GIS v 3.2 (ESRI). To examine the differences of crop damage incidents between the two parks, we 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, 1-2 km, 2-3 km and >3 km) from the park boundaries of WKNP and BBSNP, respectively.

Crop raiding severity

To determine the most parsimonious model explain the crop raiding severity, we use the Information Theoretic Approach (Burnham & Anderson 2002). We developed multiple linear regression models to determine the severity of crop damage relative to independent variables. We use size of the damaged area as a response variable in the model. Explanatory variables used in the model are described in Table 1. Multiple linear regression models were developed for BBSNP and WKNP combined and for each park separately to determine differences in the relative importance of predictor variable between the parks.

For the multiple linear regression analysis, we develop 19 combinations of model parameters for all data in both parks combined, and 13 combinations of model parameterization for each BBSNP and WKNP. We 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 & Anderson 2002). We also calculated model-averaged parameter estimates, and unconditional standard errors for each parameter (Burnham & 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. Elephant density in the parks was determined by standard dung count survey (Hedges & Lawson, 2006). We also included several interactions effect in the model parameterization to assess if there is any interaction effect occurs. All of these interaction effects were suspected to be ecologically meaningful in explaining crop raiding severity.

Table 1. Description of parameters used to describe characteristics of crop raiding by elephants.

Parameter	Description
Group (GR)	Group composition of elephants involved in crop damage (coded as single male=1; 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 crop raiding incident and the nearest park boundary
Park (PK)	The location of incidents (coded as BBSNP=0 and WKNP=1)

In both BBSNP and WKNP separately, eight parameters were combined to develop linear regression models. Single parameters and the interactions between parameters that we 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, we estimated each parameter value with a 95% confidence interval (CI) using PROC REG from SAS (SAS version 8.2).

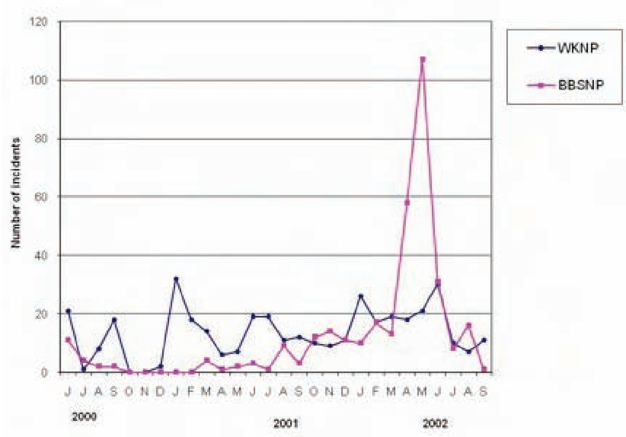

Figure 1. Total number of crop raiding incidents involving elephants in areas around WKNP and BBSNP.

Results

Crop damage assessment

During the 28 months of the study (June 2000 – September 2002), we recorded 340 crop damage incidents around BBSNP. A total of 377 crop damage incidents were recorded around WKNP. 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 22 houses during the same period, 3 people were killed, and 1 person was permanently injured. In WKNP during the same period, 2 houses were damaged and 2 persons were permanently injured. The number of incidents per month in WKNP was greater than in BBSNP (Fig. 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 centre part of the park and relatively more clustered

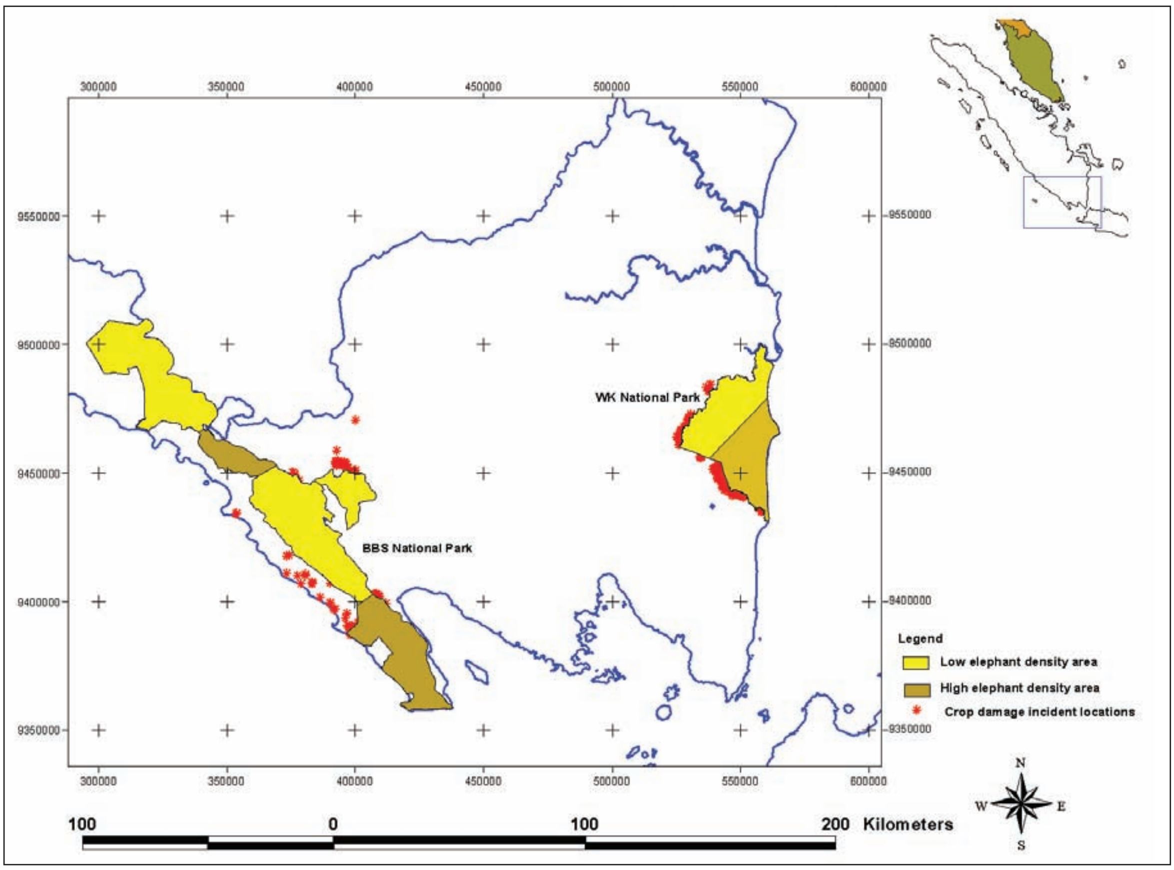

Figure 2. Distribution of crop raiding incidents around BBSNP and WKNP.

Spatial distribution of crop raiding incidents around WKNP mostly occur closer to the boundary (60% of the incidents occurring <1 km from the park's boundaries) whereas in BBSNP only 34% of incidents occur at distance <1 km from the park boundaries (Fig. 3). There was a difference between expected and observed frequencies of crop raiding incidents among the 4 distance classes for the pooled data (χ^2=49.17, 3 df, P<0.01). However, in WKNP the severity of crop raiding among the four-distance classes was different (χ^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 (χ^2=4.889, 3 df, P<0.180).

Relationship of crop raiding severity with environmental 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 (Δ AIC<2, Table 2, Burnham & Anderson 2002). Model average effect estimates for data from both parks combined showed that the variables of number of elephants 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 3). The

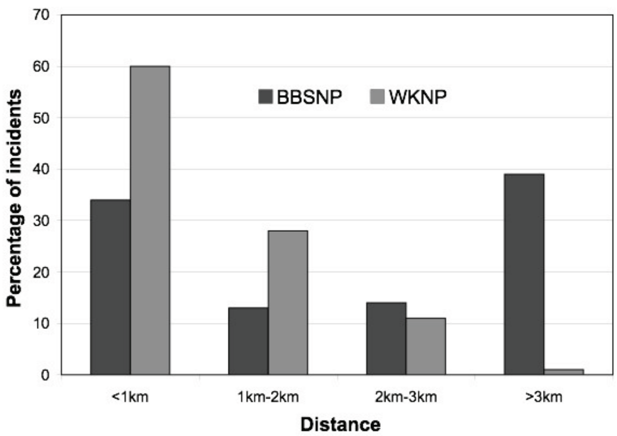

Figure 3. Distribution of crop raiding incidents by elephants relative to the distance from park boundary in BBSNP and WKNP.

Table 2. Multiple regression models for the crop damage severity by elephants for BBSNP and WKNP data combined (n = 356). Models are ranked from the highest to lowest based on Akaike's Information Criterion (*AIC*), delta (*Δ AIC*), Akaike weight (ω) and number of parameters (*K*).

Model	*AIC*	Δ AIC	ω_i	K
DT+Park +Park*DT	4768.0	0	0.466	4
DT+ED+Park +Park*DT	4768.3	0.30	0.402	5
Group+DT	4771.2	3.26	0.091	3
Park*ED	4772.9	4.90	0.040	2
Group	4782.3	14.32	0.0004	2
DT+EL	4786.5	18.50	4.49E-05	3
EL+Slope	4786.6	18.59	4.28E-05	3
Park	4789.6	21.66	9.21E-06	2
Slope+DT	4790.2	22.20	7.05E-06	3
DT+ED+Park	4790.8	22.78	5.28E-06	4
Distance	4793.3	25.34	1.46E-06	2
Elephant	4794.6	26.65	7.6E-07	2
Slope	4795.0	26.99	6.42E-07	2
Distance+ED	4795.2	27.27	5.59E-07	3
Slope*DT	4796.3	28.32	3.3E-07	2
Park*DT	4799.0	31.04	8.46E-08	2
ED*DT	4799.4	31.41	7.05E-08	2
ED	4801.1	33.15	2.95E-08	2
EL*DT	4801.1	33.16	2.93E-08	2

large negative effect of severity of crop damage is found in the group and slope parameter. This result indicated that single male elephants 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

Table 3. Multiple linear regression parameter estimates for crop damage severity by elephants in BBSNP and WKNP.

			95% CI	
Parameter	$\hat{\beta}_j$	SE	lower	upper
Intercept	48.9	279.3	-498.5	596.3
Elephant	27.8	9.4	9.5	46.2
Group	-614.1	119.6	-848.6	-379.6
Distance	0.1	0.1	-0.1	0.2
ED	398.4	701.4	-976.5	1173.2
Park	858.8	162.0	541.3	1176.4
Slope	-25.5	8.8	-42.7	-16.7
Park*DT	-0.2	0.2	-0.6	0.2
Park*ED	2045.0	372.0	1313.4	2776.6
Slope*DT	-0.01	0.004	-0.0	-0.002

parameter (ω=0.25). However, several other parameterizations involving the combination of distance with individual parameter of group, slope, number of elephant involved in the raiding and elephant density in the park adjacent to the crop raiding incidents had substantial empirical support to the model (Δ AIC<2, Table 4, Burnham & 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 SE). Other parameters (group type, 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 5).

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 (ω=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 slope parameter had considerably less empirical support (4<Δ AIC<10, Table 6, Burnham & Anderson 2002). Model average of parameter estimate for crop raiding in WKNP indicated that number of elephants involved in the raiding incidents, and elephant density in the park adjacent to the crop raiding location had large effects on the severity of crop damage (Table 7). Negative effects of other parameter to the severity of crop damage were found in group, distance and the interaction between slope and distance parameter. Slope parameter had no effect in the crop damage severity in WKNP.

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

Table 4. Multiple regression models for the crop damage severity for BBSNP (n= 108).

Model	*AIC*	*Δ AIC*	ω_i	*K*
Distance	1366.7	0	0.25	2
Elephant+Distance	1367.5	0.81	0.17	3
Slope+Distance	1368.1	1.38	0.13	3
Group+Distance	1368.5	1.78	0.10	3
ED+Distance	1368.7	1.99	0.09	3
Group	1370.4	3.63	0.04	2
ED	1370.5	3.74	0.04	2
Slope	1370.5	3.75	0.04	2
Elephant	1370.7	3.98	0.03	2
ED*Distance	1370.8	4.06	0.03	2
Elephant*Distance	1371.1	4.35	0.03	2
Elephant+Slope	1371.5	4.73	0.02	3
Distance*Slope	1371.6	4.87	0.02	3

Table 5. Multiple linear regression parameter estimates for crop damage severity in BBSNP.

			95% CI	
Parameter	$\hat{\beta}_j$	SE	lower	upper
Intercept	114.4	127.8	-136.0	364.8
Elephant	-10.1	9.7	-29.0	8.9
Group	-104.1	168.3	-433.9	225.7
Distance	0.07	0.03	0.004	0.13
ED	-151.9	246.4	-634.7	331.0
Slope	-7.1	6.8	-20.4	6.3

Table 6. Multiple regression models for the crop damage severity for WKNP (n= 248).

Model	*AIC*	*ΔAIC*	ω_i	*K*
Elephant+DT	3346.4	0	0.912	3
Group+DT	3351.8	5.39	0.061	3
Elephant	3354.5	8.10	0.016	2
Elephant+Slope	3355.3	8.84	0.011	3
Group	3365.0	18.60	8.33E-05	2
ED+DT	3367.9	21.42	2.04E-05	3
Slope+DT	3371.2	24.79	3.78E-06	3
Distance	3371.4	24.92	3.54E-06	2
ED	3375.8	29.37	3.82E-07	2
DT*Slope	3376.3	29.91	2.91E-07	2
Slope	3386.5	40.07	1.81E-09	2
Elephant*DT	3387.3	40.85	1.23E-09	2
ED*DT	3388.0	41.58	8.54E-10	2

Table 7. Multiple linear regression parameter estimates for crop damage severity in WKNP.

			95% CI	
Parameter	$\hat{\beta}_j$	SE	lower	upper
Intercept	530.4	169.0	199.1	861.6
Elephant	77.2	14.6	48.6	105.8
Group	-614.3	119.6	-848.7	-379.9
Distance	-0.21	0.06	-0.34	-0.08
ED	1660.3	710.5	267.6	3052.9
Slope	-163.8	146.8	-451.5	123.8
Slope*DT	-0.27	0.07	-0.41	-0.13

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). 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. Results of our 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. 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 about 10% elephant habitat quality in the park (Bintoro, Head of WKNP, pers. comm.). 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).

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 (Figs. 2 & 3). 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 of BBSNP (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.

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 (Figs. 4 & 5), 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 and 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. While in WKNP, the elephants easily know when they are outside the park because the landscape is so different between the inside and

Figure 4. Damaged banana tree in BBSNP.

Figure 5. Damaged rice field in WKNP.

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.

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 (Δ AIC<2, Table 2). 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 are 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 group of elephant tend to cause more severe damage than single elephant. 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. There are four major factors cause this phenomenon in WKNP. First are crop-raiding elephants that travel in large groups obviously causing more damage in crops because there are more individuals involved in crop raiding. 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. Third, there is a possibility that crop-raiding elephants that 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).

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 spatial and temporal pattern of the crop raiding in both parks is 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. We suggest minimum 500 m from the park boundary should be established as a buffer zone along the park. Palatable crops such as rice, maize and cassava should be planted farther away from park boundary (eq. more than 1 km from the 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 our 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. The optimum distance between each tower is depends on the topography and vegetation cover along the park boundary. If topography is flat and open vegetation, minimum distance of 500 m between towers is probably suitable to detect elephant before entering the crop field.

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, we believe that conflict management should focus on decreasing the possibility of elephant to 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" (Fig. 6) to mitigate crop raiding in both parks 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 specific for each park -even in the same province of Sumatra- 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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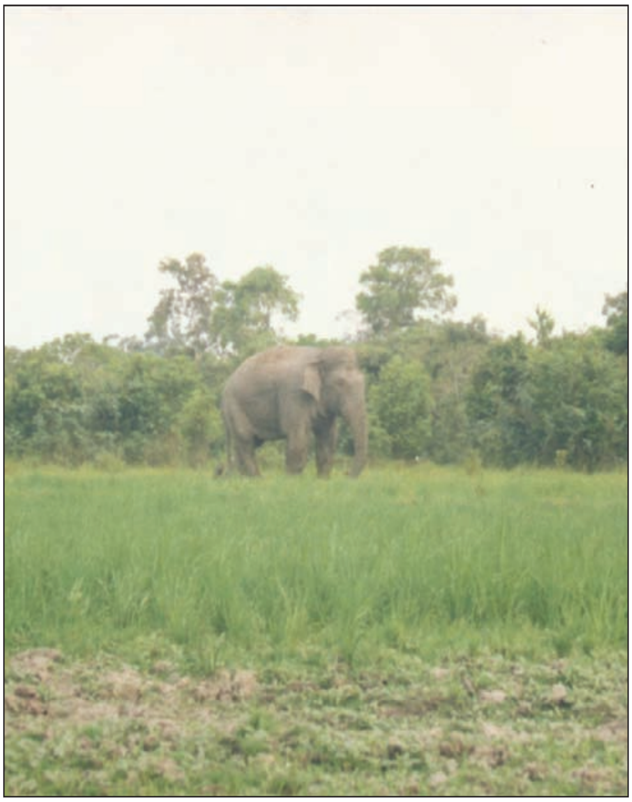

Figure 6. Adult bull raids rice field in WKNP.

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