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A simple method for calculating the likelihood of crop damage by primates: an epidemiological approach

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Human–wildlife conflict, specifically crop raiding by wildlife, is an increasing concern. Primates are a particular problem across much of Africa and Asia, especially for rural, subsistence farmers living and farming at the forest edge. Most methods designed for sampling and extrapolating from primate crop damage in a subsistence farming context require extensive data collection and involve considerable expenditure of time to complete data analysis. Using a standard epidemiological model, we predict the relative risk of primate crop raiding based on crops grown, their availability within individual farms and patterns of primate selectivity. The model produces an index of relative risk of crop raiding by primates within a geographical region. It rapidly ranks farms according to their vulnerability to crop raiding, with limited need for in-depth data collection. It will therefore allow a more effective deployment of protection methods and more pro-active targeting of resources. This method of modelling primate crop damage can be taught to local communities rapidly and easily. Although not designed to replace existing methods, it can run effectively in conjunction with them.

Keywords: primate; conservation; crop raiding; epidemiological modelling; human-wildlife conflict; risk; Sulawesi

1. Introduction

Human–wildlife interaction is now recognised as a major issue in conservation (IUCN 2005). Crop raiding is a widespread and common example of human–wildlife conflict and crop damage directly influences local people's perception of, and support for, conservation initiatives (Conover and Decker 1991; Hill 1998).

Many animal species raid agricultural crops. Insects, rodents, birds and antelope are those most frequently cited in the literature, most likely due to the impact they have on cash crops and intensive agriculture (see, e.g. Cameron et al. 1986; Clark and Young 1986; Jepsen 1991; Khokhar et al. 1993; Conover and Kania 1995; Rice and Ostlie 1997). However, in areas of the tropics of high conservation concern where local people are mainly subsistence farmers, primates are commonly cited as significant pests (Horrocks and Baulu 1994; Strum 1994; Naughton Treves 1996; Hill 1997; Priston 2005). Increasing competition between humans and non-human primates is a major problem facing primate populations in the developing world. Human and non-human primate niches overlap extensively, making the possibility of competition between the two much higher than for other species, and posing many management problems (Strum 1987).

1.1. Primates as pests

Crop damage is an increasing source of economic loss and local frustration in subsistence agriculture settings and also promotes negative attitudes towards species of conservation value. Primates dominate amongst pests that damage crops, particularly around African and Asian reserves, being responsible for over 70% of the measured damage events and 50% of the area damaged (Naughton Treves 1998b). Crop losses to primates can be as much as 70% of an individual farm (Priston 2005) and average losses of certain crops at other sites have been measured at 19–25% of the annual crop (Hill 2000). Because of their intelligence, opportunism, adaptability and manipulative abilities many primate species easily turn to crop foraging and make formidable crop raiders (Lee and Priston 2005). Crop raiding is variable in intensity and difficult to measure (Naughton Treves 1998a, 1998b) and is also site-specific.

1.2. Patterns and causes of primate raiding

With the increasing size of human populations living in areas of high biological diversity and endemism, this form of conflict is likely to increase (Mittermeier et al. 1999; Cincotta et al. 2000; Myers et al. 2000; Balmford et al. 2001). Due to its site-specificity,

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management of crop raiding can be very difficult. Local conditions will play a major role in determining which areas are raided. Rainfall, season, crop variety and characteristics, wild-food availability, distance from forest, distance from other farms or the village, and farm protection methods, all affect raiding of farms by wildlife (Mohnot 1971; Maples et al. 1976; Musau and Strum 1984; Gautier-Hion et al. 1985; Horrocks and Baulu 1994; Naughton Treves 1998b; Hill 2000). Troop size and individual characteristics of the primate (age, sex, experience, motivation) may also be important; for example, in olive baboons (*Papio anubis*), young adolescent males were found to be the most frequent raiders (Oyaro and Strum 1984; Forthman Quick 1986; Strum 1994).

1.3. Measuring damage to crops by primates

Existing methods of quantifying primate crop damage and of identifying areas of risk depend on long-term data collection. Methods include measuring percentage damage over a large area through the use of a grid system (Naughton Treves 1996; Naughton Treves 1998a; Webber 2006; Linkie et al. 2007), sampling of specific stands of crops (Hill 2000; Warren et al. 2007), using vegetation transects or plots (Siex and Struhsaker 1999; Priston 2005) or behavioural observations (Maples et al. 1976; Warren 2003; Chhangani and Mohnot 2004; Priston 2005). GIS data can also be collected and used to model the likelihood of raiding in certain areas (Webber 2006). The data can then be extrapolated from and used to predict factors which may contribute to increased primate crop raiding.

Data obtained by the aforementioned methods take many months, if not years, to collect, and require either ongoing research presence or lengthy training of local farmers. Whilst they may provide the most accurate method of predicting local crop damage, such intensive efforts may not be possible in all locations due to funding or time constraints. When local people need to make management decisions or decisions as to where to invest their time protecting crops a 'simple rule of thumb' method of assessing relative-risk is desirable.

1.4. An alternative

We propose the use of a rapid, easily implemented model for predicting the likely frequency of crop raiding damage based on the type of crop being grown. Studies have shown crop type to be one of the most significant factors in predicting crop damage (Naughton Treves 1998a; Hill 2000; Priston 2005) and as such could act as a proxy for other more complex factors, particularly in areas where all farms are located near to a protected area. Crockett and Wilson (1980) described how pig-tailed macaques exhibit a preference for sweet potato and maize in Sumatra. In studies of African agricultural areas (Naughton Treves 1998a; Hill 2000) and Buton (Sulawesi, Indonesia) (Priston 2005) farmers have reported heavy losses to primates of maize and sweet potato and measures of actual crop loss support these reports. Maize and sweet potato are staple, subsistence food crops and, in some of these studies, they were also the most abundant crop in the farms (Hill 1997; Saj et al. 2001). However, there are data to suggest that such a preference by monkeys is real and not merely a reflection of the abundance of those crops (Naughton Treves 1996). Maize presence is a predictor of crop damage (Naughton Treves 1998a; Saj et al. 2001) and primates will raid maize regardless of the abundance of forest foods (Naughton Treves 1997; Naughton Treves 1998b). Maize and sweet potato are easily carried crops with high calorific returns for low harvest effort; cultivated maize also has elevated protein content (12%) (Sukumar 1989). Bananas are also cited in some studies as a preferred crop of some raiding primates (Naughton Treves 1998b). Yellow, orange or red, softer-skinned fruits are preferred by primates (Gautier-Hion et al. 1985; Horrocks and Baulu 1994) suggesting that, for certain crops, physical characteristics as opposed to merely nutritional content may also govern choice. The proportion of simple sugars to other carbohydrates is, also likely to be important, as simple sugars increase with ripeness, accompanying skin and colour changes (Horrocks and Baulu 1994).

Here we present a commonly used epidemiological model and apply it primate crop raiding. The model uses crop susceptibility to predict the frequency of crop damage in a subsistence-farming context, and hence relative raiding risk, in a simple way. The model is a simple, quick means for local people and conservation managers to make decisions about how to direct efforts to control the problem. The use of epidemiological modelling to address the problem of primate crop raiding has a number of advantages over traditional sampling techniques. Firstly the model can be applied across the geographical spectrum without the need for modification and secondly it can be used by local farmers without the need for time-consuming data collection and complex analyses. One of the most common complaints of local people towards researchers is: 'How will this work help me?'. The model can be taught to local farmers, community leaders or conservation managers by field researchers in conjunction with other techniques. This combination of existing methods with our new model should go a considerable way towards including local people in the work of researchers in the field. It should be noted that this model is not designed to predict farmer's perceptions of crop raiding risk; rather, it predicts actual risk.

2. Materials and methods

Incidence rate is the fundamental measure in epidemiology being the frequency of new occurrences of a disease event, within the population of study, within a specified period of time (Bhopal and Last 2002). Raiding can, and does, have differential rates of occurrence; therefore the single incidence rate at any given time is used here, as opposed to the cumulative incidence rate, because of the distribution of raid events within the sample. The incidence rate IR (risk of raiding) is calculated using the simple formula:

$$\mathrm{IR} = \frac{\text{New Occurence over a period of time } (a)}{\text{Population at risk over that period of time} (a+b)}$$

The incidence rate is an extremely flexible measure, not requiring adherence to model distributions of events and is therefore very well suited to the nature of crop raiding events.

The model intentionally relies upon a very simple method of data collection that can use all the plants on a small farm or representative transects from larger ones. Plants are categorised as either available or unavailable to primates. Availability is defined as whether or not the plant is in a state that would induce primates to consume the plant part (i.e. ripe fruit, edible leaf, tubers present, versus unripe, inedible, no tubers etc). Crops within each farm were recorded as follows:

- Crop absent from the farm or unavailable to primates.
- Crop present in the farm and available but not damaged.
- Crop present, available and damaged.

These data are then pooled across farms to give the total number of farms on which each crop is damaged (a), and the total number of farms on which each crop was present and available to crop raiding primates (b). This provides the data that will be used as the denominator and the numerator. The risk of a crop being raided can be calculated by using the number of farms on which that crop was damaged by crop raiding primates (a) as the numerator, and the sum of all the farms on which that crop was damaged and the number of farms that crop was present and available in ($a + b$) as the denominator. The same calculation is repeated for all of the crops on each farm to provide the risk of raiding according to crop. The data can then be used to identify the crop species at greatest risk from primate raiding. Higher risk crops will have an IR closer to 1. Using basic probability theory the risk values are then summed for all crops present on a farm. Total risk values for farms can therefore exceed one because they are relative figures. It is then possible to rank farms in order of the likelihood of experiencing raiding and identify the farms or areas on farms at greatest risk. This allows defence mechanisms to be concentrated more effectively.

The data used to calculate the incidence rate of raiding for each crop were collected between May and September 2002 and were based on vegetation transects in 72 farms, subject to crop raiding by the Buton Macaque (*Macaca ochreata brunnescens* Matschie, 1901) in Central Buton, south east Sulawesi (Priston, 2005). All farms were within 1km of the Lambusango Reserve (Suaka Margasatwa Lambusango). Along each transect all crops were counted and scored according to level of crop damage and availability to primate raiders. Any crop with fewer than five plants damaged was excluded from the analysis in order to avoid skewing the data towards rare crops present in only small quantities in the farm (Priston 2005). Transects were then summed across farms for the purposes of this model, to give a farm level indicator of which crops were damaged on a farm. It should be noted that this does not take into account severity of damage.

The model was then validated and tested using independently collected data, taken from the same region in a different year. Data were collected between June and August 2004 from 43 farms located in the same geographical region in Central Buton, again all within 1km of the Lambusango Reserve. The model was used to predict the relative risk of raiding based on crops present, and ripe in the farms. This was then compared to ‘actual’ damage based on vegetation transects (as above) using a two-tailed, Spearman’s rank correlation with a significance value of $P = 0.05$.

3. Results

The crops included in the analysis are listed in Table 1. Based on the farm data, the risk of raiding for each crop was calculated and expressed as a proportion. Maize, sweet potato and papaya were revealed to be at a substantially greater risk of raiding than other crops. This closely reflects results from other primate crop raiding studies (Hill 1997; Naughton Treves 1997, 1998a; Hill 2000) and is also supported in this study site by independent observations of crop raiding through behavioural studies of the primates, which showed a preference for these three crops above others (Priston 2005).

Once the initial risk of raiding has been calculated, the model can then be applied to other farms in the area, during that season. The presence or absence of each crop must be noted and then the risk of raiding can be calculated through summing the risk of raiding for each crop. An example is presented in Table 2. This hypothetical example demonstrates how relative risk can be calculated simply and quickly.

Table 1. Calculated prevalence of crop damage by crop species.

Crop	Number of farms with crop absent	Number of farms with crop raided (Numerator) (a)	Number of farms with crop present but not raided (b)	(Denominator) $a + b$	Risk of raiding (IR) a $(a + b)$
Aubergine	57	6	9	15	0.40
Banana	33	9	30	39	0.23
Beans	55	5	12	17	0.29
Cassava	54	3	15	18	0.17
Chilli	46	0	26	26	0.0
Cocoa	49	5	18	23	0.22
Coconut	47	4	21	25	0.16
Maize	59	12	1	13	0.92
Papaya	51	11	10	21	0.52
Peanut	67	1	4	5	0.20
Pumpkin	66	2	4	6	0.33
Sugar cane	51	2	19	21	0.095
Sweet potato	44	18	10	28	0.64
Taro	51	4	17	21	0.19
Tomato	63	0	9	9	0.0

Validation of the model revealed a strong, significant positive correlation between the relative risk predicted by this model and the actual levels of crop damage experienced on each farm (Rs $= 0.9482$, $n = 43$, $P < 0.001$) (Table 3).

4. Discussion

We have demonstrated that a simple epidemiological measure can successfully predict relative risk of primate crop raiding based on the types of crops grown and their availability. Used in conjunction with longer-term traditional analytical methods, it can provide a rapid tool to assist in local peoples' management of wildlife crop raiding. Our results provide compelling evidence that this model is a useful tool for predicting relative risk within geographical regions. While these specific risk figures are not directly applicable to other sites they do provide an example of the efficacy of this approach. As crop raiding is both season- and region-specific (in terms of raiding species and crops grown) we are not suggesting this model to be a replacement for all measures of crop damage globally. Instead it could be used in cases where data are available from work that has already been conducted in one area and there is a need to make management decisions elsewhere within the same region. It could also be useful in small-scale studies, the results of which could be used to estimate the raiding risks which, through local community involvement, could be applied to a much wider area. It is applicable to animals other than primate species and could also be used for non-primate crop raiding species, such as elephants, wild pigs and other ungulates with identifiable and characteristic patterns of raiding. Once again, we emphasise that this model is designed to provide a simple tool for local people who lack scientific training, to enable them to better manage their crop raiding prevention strategies or for local conservation groups to better target limited funds, and not as a replacement for existing traditional academic methods. The model cannot be used to predict farmer's perceptions of crop raiding risk, and as with other models, an obvious problem is that the resultant targeting of management strategies to high risk areas may cause primates to shift their raiding patterns and raid elsewhere. This is something that would need to be mentioned to individuals or local conservation managers using the model, so that they can adjust their management strategies appropriately (i.e. whilst focusing on high risk areas, other areas still need to be included in the management strategy). The model provides a simple proxy for crop raiding risk that can be executed with pen and paper calculations, by local people without access to computers or prohibitively expensive statistical software. It can provide quickly obtainable benefits in real time.

Table 2. Hypothetical example of application of model to produce risk of crop raiding for three farms.

Farm	Crop present	Risk of raiding for crop	Total risk of raiding for farm
1	Banana	0.23	1.34
	Maize	0.92	
	Taro	0.19	
2	Banana	0.23	1.04
	Sweet potato	0.64	
	Cassava	0.17	
3	Aubergine	0.40	0.81
	Tomato	0.0	
	Beans	0.29	
	Papaya	0.52	

Table 3. Results of model validation demonstrating correlation between the rank of total risk and the rank of actual damage

Farm	Total relative risk of raiding (based on crops present)	Measured (actual) percentage damage	Rank of total risk	Rank of actual damage
1	0.6	10.3	15	13
2	1.5	15.8	26	18
3	2.4	42.4	36	34
4	1.9	27.6	30	28
5	0.4	8.3	8	9
6	2.4	60.0	37	41
7	2.4	51.6	34	38
8	2.3	40.9	32	33
9	2.0	37.7	31	32
10	1.4	22.0	24	24
11	0.4	6.3	6	6
12	0.2	3.0	2	3
13	1.2	15.9	20	19
14	0.9	7.4	17	8
15	3.9	76.5	43	43
16	0.2	4.0	3.5	4
17	2.4	43.2	35	35
18	0.3	0.0	5	1.5
19	0.2	0.0	1	1.5
20	0.2	10.0	3.5	12
21	3.0	70.0	42	42
22	1.3	27.6	21	27
23	2.3	27.3	33	25
24	1.4	30.5	25	30
25	2.8	45.6	41	36
26	2.7	47.0	40	37
27	1.9	20.0	29	22
28	1.4	16.9	22.5	20
29	2.5	56.7	39	40
30	1.9	27.8	28	29
31	0.6	12.0	12	15
32	0.6	8.5	12	10
33	0.6	11.8	12	14
34	2.4	56.0	38	39
35	1.4	36.7	22.5	31
36	1.1	20.0	18.5	22
37	1.1	20.0	18.5	22
38	0.4	7.1	9	7
39	0.6	12.2	12	16
40	0.6	13.4	12	17
41	0.4	6.3	7	5
42	0.8	9.5	16	11
43	1.8	27.5	27	26

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