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Nancy E. C. Priston [a]
[a] Department of Anthropology and Geography, Oxford Brookes University, Oxford, UK

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Exclosure plots as a mechanism for quantifying damage to crops by primates

Nancy E.C. Priston*

Department of Anthropology and Geography, Oxford Brookes University, Oxford, OX3 0BP, UK

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Human-wildlife conflict is a major issue for conservation biologists in the twenty-first century. Crop-damage by wild animals is one element of this conflict, often causing local farmers considerable economic loss and frustration, and undermining local conservation efforts. Formulation of suitable management strategies necessitates accurate measures of crop-damage to allow prioritisation of management efforts and decisions. There is a relative paucity of information from subsistence agricultural settings in Asia. This study represents the first attempt to measure systematically the impact of damage by monkeys to sweet potato crop yields using exclosure plots (3 × 3 m) on Sulawesi, Indonesia. The Buton macaque, *Macaca ochreata brunnescens*, was responsible for less crop-damage than wild pigs, both in terms of the number of tubers (primates: 35%, pigs: 65%) and total harvested weight (primates: 13%, pigs: 85%). This study also highlights some methodological limitations of exclosure studies and reveals that the exclosures themselves affect crop yields, reducing them by up to 50%. This suggests that estimates of damage should actually be slightly greater; caution should therefore be exercised in the use of such techniques.

Keywords: Buton macaque; crop-raiding; exclosure plots; human-wildlife conflict; *Macaca ochreata brunnescens*; South East Sulawesi; Buton

1. Introduction

Areas of conservation importance often occur in areas of high human population density (Cincotta et al. 2000; Myers et al. 2000) and local human development needs can challenge conservation priorities (Balmford et al. 2001). Communities bordering protected areas may suffer loss of economic opportunities, including exclusion from potential resources and damage and depredation to crops and livestock by wild animals (Infield and Namara 2001). Historically, human–wildlife interactions have tended to result in human 'victory' over animal 'combatants' which were subsequently excluded from traditional areas or eliminated altogether (Southwick et al. 1983). Although nowadays there is a shift from this attitude, the view is still present to a certain extent, particularly among local people subjected to crop loss on a daily basis (Lee and Priston 2005). This 'eco-war' is subsumed under the concept of 'conflict' which only humans can ultimately win (Lee 2004). Where a local people's crops are subject to wildlife damage this directly affects their perceptions of and support for conservation initiatives (Conover and Decker 1991). Recent studies have begun to address these issues and incorporate them into management plans for reserves and national parks (see for example Bell 1984; Newmark et al. 1993, 1994; Fiallo and Jacobson 1995; Naughton Treves 1997; De Boer and Baquette 1998; Gillingham and Lee 1999, 2003; Hill et al. 2002).

Primates, particularly cercopithecoids (Old World monkeys), are one of the most frequently cited crop pests (Naughton Treves 1998; Hill 2000; Gillingham and Lee 2003). Macaques, in particular, are commensal with humans across their whole range and possess traits which enable them to successfully exploit agricultural resources. Macaques vary in the extent to which they are terrestrial or arboreal (Fleagle 2003). Those which are primarily terrestrial with an ability to exploit arboreal habitats, are particularly well suited to crop-raiding. Macaques are also opportunistic frugivores and possess cheek pouches to store food. They can, therefore, maximise food acquisition by using these pouches as well as their hands to carry food away from feeding sites to consume later on, in less risky sites or away from other members of the group (Sillero-Zubiri and Switzer 2001).

Although Asia is recognised as having generally low primate species richness (Cowlishaw and Dunbar 2000), 44% of the world's 25 most endangered primates are endemic to this region (Mittermeier et al. 2007). Mittermeier classes Indonesia as a country exhibiting megadiversity (Mittermeier et al. 2004); it is home to the second highest number of primate species (Cowlishaw and Dunbar 2000). Indonesia is also a region of high human population density, and has the sixth largest human population in the world (CIA-WFB 2006). Sulawesi lies in the biogeographical region of Wallacea, which is listed as a 'Biodiversity Hotspot' (Myers et al. 2000) due to its great diversity of endemic

*Email: nancy@cantab.net

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species and, at the same time, significant impact and alteration by human activities (Mittermeier et al. 1999). Sulawesi is one of the most distinctive islands in the region with 127 indigenous mammals, 79 of which are endemic (Whitten et al. 2002). Almost all of Indonesia's lowland forests have already been exploited by commercial loggers (Myers 1984) and what remains continues to be degraded annually (Johnson and Cabarle 1993). Between 1991 and 2004, forest cover on the Southern half of Buton Island, where this research took place, declined by 20% (B. Carlisle, pers. comm.). Although macaques can cope with deforestation better than some other primates (Richard et al. 1989), all seven species of Sulawesi macaque are threatened by habitat loss or hunting (often as agricultural pest control) with some populations experiencing a 75% decline over 15 years (e.g. Sulawesi crested macaque, *Macaca nigra*: (Rosenbaum et al. 1998)).

Despite primates causing considerable human wildlife conflict across Asia, Africa and South America there is a relative paucity of literature quantifying primate crop-damage in subsistence agricultural settings, especially in Southeast Asia (Linkie et al. 2007). This is in part due to the fact that it is extremely difficult to collect these data, particularly in a way which is not overly labour-intensive. Common methods for measuring damage include: (i) employing a grid system to assess percentage damage over a large area (Naughton Treves 1996, 1998; Webber 2006; Linkie et al. 2007), (ii) sampling of specific stands of crops (Hill 2000; Warren et al. 2007), (iii) the use of vegetation transects or plots (Siex and Struhsaker 1999; Priston 2005). Behavioural observations have also been used in order to estimate crop-damage based on feeding observations of primates (Maples et al. 1976; Warren 2003; Chhangani and Mohnot 2004; Priston 2005). These techniques are time-consuming, labour-intensive, and can be subject to error as it is often hard to determine the species responsible for loss if measuring it a week or more after the event. The likelihood of inter-observer error in assessment of quantity and severity of damage is also high. If relying on farmer reports, there is the additional issue of potential over or under-reporting which requires continual checking to ensure accuracy (Linkie et al. 2007).

Exclosure plots, (areas of land from which certain animals are excluded, Hone 1994), allow crop-damage to be quantified. They have been used to significant effect in the investigation of damage to cash crops by rabbits in Australia (Hone 1994), by birds, deer, rabbits, bear and groundhog in North America (Drake and Grande 2002). They have also been used to assess geese damage to cereals (Borman et al. 2000, 2001), deer damage to forestry (Gary et al. 2000), and in the context of wildlife management schemes in North America (National Park Service 1997; Conover 2002). However, this is the first study to use exclosure plots to make a systematic assessment of damage to and impact on crop yields by primates in tropical forest environments. A previous study (Rao et al. 2002) used similar techniques but focused on damage by all vertebrate species concurrently.

2. Materials and methods

The island of Buton is situated off the Southeast coast of Sulawesi (longitude 123° 12′ E–122° 33′ E and latitude 5° 44′ S–4° 21′ S) (Figure 1). It is approximately 4520 km^2 and covered with moist, deciduous, lowland forest on limestone karst (Whitten et al. 2002). Average annual rainfall is 2012 mm, and during the study period there was an average of 43 mm rainfall per month (Badan Meteorologi dan Geofisika, unpublished data, Priston, unpublished data). Its human population of approximately 450,000 consists of native Butonese Muslims (over 86%) (Whitten et al. 2002; Palmer 2004), transmigrants from various islands including Bali (Hindus), Java and Ambon and a small number of Christians (pers. obs.). The main agricultural products are maize (*Zea mays*), cassava (*Manihot esculenta*), rice (*Oriza sativum*) and fruit (especially citrus). The majority of the population is engaged in subsistence farming (Whitten et al. 2002).

Exclosure plots were constructed on two sweet potato farms in the village of Kawelli, central Buton, (122° 51′ 03″ E, 5° 11′ 14″ S) between June and September 2003. The village is within 5km of the Kakenauwe (810 ha) and Lambusango reserves (28,500 ha) (Figure 1), designated as *Cagar Alam* (nature reserve) and *Suaka Margasatwa* (wildlife and hunting reserve), respectively. One farm which was raided regularly by both wild pigs and macaques, and another farm which was not raided at all, were chosen (based on both personal observations and farmers' reports). The farms were matched in terms of distance to forest, size, crop type and density, stage of crop ripeness, and level of human activity. Agreements were made with the two owners of the farm that no active guarding would take place during the study period. There was no new planting, repairing of fences (which were all in good condition) or harvesting during the study. Twelve 3 × 3-m plots, constructed following Drake and Grande (2002), were placed on each farm; the control and raided farm. Exclosures were designed primarily to assess primate (Buton Macaque, *Macaca ochreata brunnescens*) damage, however pig damage was also quantified (Sulawesi warty pig, *Sus celebensis*, and feral domestic pigs, *Sus scrofa*). Smaller pest species such as rats had equal access to all plots, although it is recognised that such pests may have preferred the fenced and meshed plots because of the potential protection from aerial predators. Visual inspections however suggest small pest damage to be similar both inside and outside the plots. Levels of small mammals and other commensal pests may be influenced by distance from human habitation but

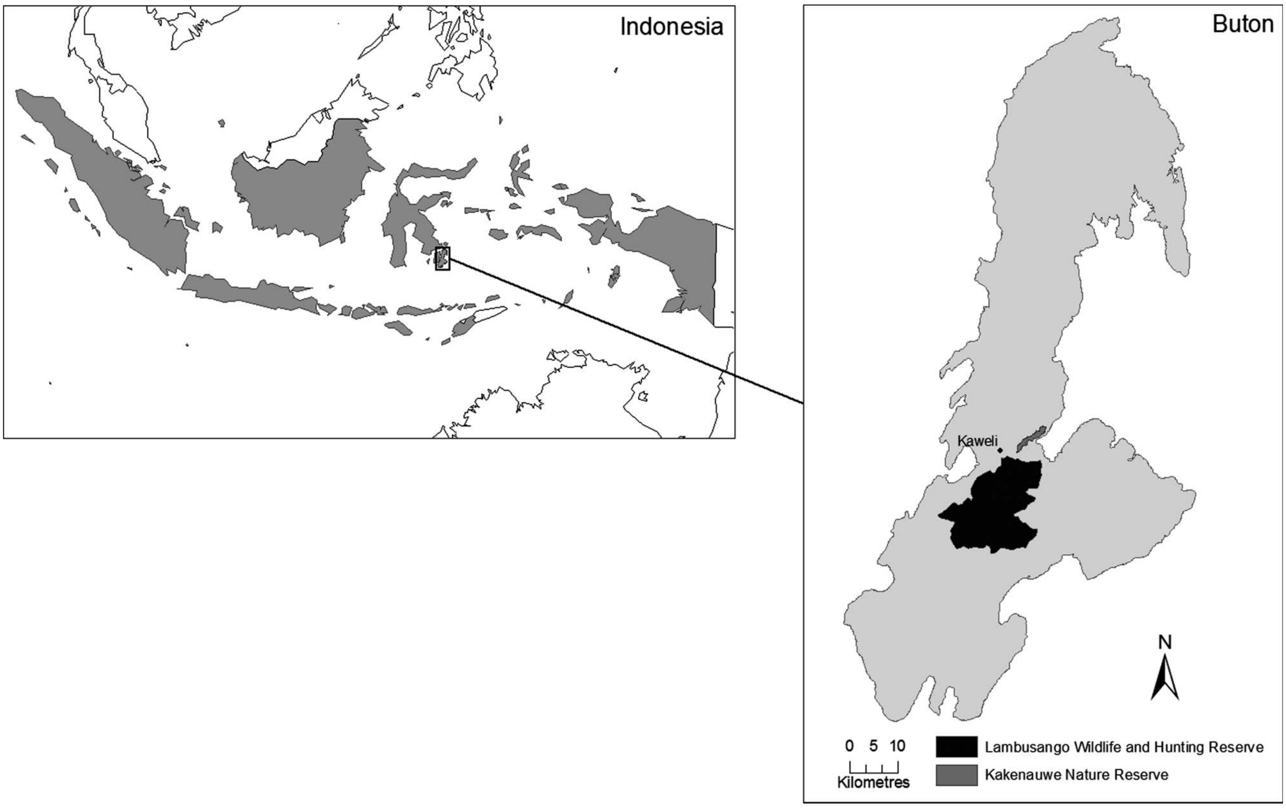

Figure 1. Location of the study site in Buton and within Indonesia.

within this study both farms were the same distance from the village.

Plots were of three types: (i) fence and mesh plots (mesh plots) – fenced and topped with mesh to exclude pigs and monkeys; (ii) fence plots –fenced and left open on top, to exclude only pigs; and (iii) open plots – staked out as controls for location in fields.

Fences were made from solid planks of wood and were 1.5 m high above ground and buried 30 cm into the ground to prevent pigs digging beneath. Two inch square gauge chicken wire was used for the mesh; this was deemed sufficiently large to enable rats to enter by a rodent expert working in the region (N. Grimwood, pers. comm.). Three fence and mesh and three fence-only plots were set up at randomly selected locations within each farm after planting had taken place and the sweet potato had grown to significantly cover the available ground. In order to control for any intra-farm differences in crop growth, an open plot was staked out next to each of these, leaving a one metre gap between the two. Exclosures were left until the usual sweet potato harvest time (which for this year was September) when potatoes were removed, counted and weighed using a 20-kg spring balance. These numbers and weights were then converted to number/weight per m^2 for comparison.

Mean yields, in terms of total weight and number of tubers per m^2, were calculated for each plot type in both the control and raided farm. Data were entered into aSPSS version 10 spreadhseet and differences between plots and farms were tested using one-way ANOVA. Levene's test for homogeneity of variance was applied, and when variances were equal Scheffe's *post-hoc* test was employed. The latter test protects against a Type 1 error and is designed to allow all possible linear combinations of group means to be tested, not just pairwise comparisons, resulting in a more conservative test and requiring a larger difference between samples for significance. Scheffe's test is also appropriate for use with groups of unequal sample size. When variances were significantly different between groups, Tamhane's T2 test was used; this is a conservative pairwise comparisons test based on a *t*-test (Field 2000).

The difference in sweet potato yield between the plots was calculated. Only monkeys had access to the fence plots therefore all reduced yields can be attributed to them (it was assumed all other pests had an equal effect on all plots). Both pigs and monkeys had access to the open plots and it was assumed pig-raiding did not affect monkey-raiding (as pigs were only witnessed to raid at night, whilst monkeys only raided during the day). Therefore, subtracting open plot yields from fence plots estimates pig damage and subtracting fence yield from mesh yield provided an estimate of monkey damage. The mesh plots provide an estimate of potential yield with no large vertebrate damage. Percentage damage by monkeys and pigs was calculated from these figures.

Focal farm surveys were conducted during this study period (Priston 2005). Farms were observed daily from 06:00 until 17:00 h, from a discrete watch hut and all instances of crop-raiding by monkeys recorded. Instantaneous scan sampling was used to record macaque behaviour within the farm. The results are not presented here (see Priston, 2005), however these observations served to confirm usage of the plots by monkeys.

3. Results

Wild pigs and monkeys damaged on average 17.22% of the total possible yield of sweet potato. Pigs caused more damage to sweet potato than did monkeys, causing 65% of damage compared to 35% by monkeys. Pigs were responsible for 87% damage by weight compared to 13% for monkeys (Table 1).

For the raided farm the number and total weight per m^2 differed significantly between plot types (Table 2). Open plots matched with fence plots had significantly lower yields than both fence plots and mesh plots (Scheffe *post-hoc,* $P = 0.023$ and $P = 0.014$, respectively) for both measures. Open plots matched with mesh plots had significantly lower total weight per m^2 of sweet potato compared to fence and mesh plots (Scheffe *post-hoc,* $P = 0.037$ and $P = 0.024$, respectively). There was no significant difference between fence plots and mesh plot yields, although mesh yields were typically higher. On the control farm, no significant differences were found between the plots for either of the measures (Table 2).

However when considering all plots, a significant difference was found between the raided and control farms (Table 3). Although not significant, generally yields from the control farm mesh plots were higher than those of the raided farm (Table 1). Mean sweet potato yields in the absence of large vertebrate raiding were between 12.26 (raided farm, mesh plot mean) and 32.00 (control farm, open plot mean) sweet potato per m^2 (Table 2). Since the control farm received little or no raiding (supported with regular observations of the farm and crop checks) one would expect the yields from the three plot types to be similar. However, although not significantly so, the open plots had consistently higher yields than the fenced plots, and fenced plots more than mesh plots (Table 2).

Focal farm observations revealed that although monkeys did indeed forage within the fence plots it was almost a month after their installation before they seemed comfortable doing this. During crop-raids the monkeys were also observed to not only consume tubers within the plots but also to dig up several small tubers and carry them in their hands and cheek pouches to the edge of the forest before consuming them.

4. Discussion

Exclosure plots revealed that both pigs and monkeys reduced potential harvests of sweet potato in this area of Indonesia dramatically. Pigs appeared to cause more damage to sweet potato than did monkeys, and were responsible for approximately 65% of sweet potato tuber damage compared to 35% by monkeys. Monkeys damaged 0.74 potatoes per m^2, while pigs damaged 1.37 potatoes per m^2. Wild pigs may also have been damaging the bigger tubers preferentially which would explain the difference in damage weights (Table 3), but this cannot yet be demonstrated conclusively.

Table 1. Amount of yield loss attributable to large vertebrates from results of exclosure plots in the raided farm (these figures are likely to be under-estimates of total yield loss and should therefore be treated as minimum yield loss figures).

Mean	Yield in absence of large vertebrate damage	Yield loss attributed to monkeys	Yield loss attributed to monkeys and pigs	Yield loss attributed to by pigs	Percentage yield loss by monkeys	Percentage yield loss by pigs
Number per m^2	12.26	0.74	2.11	1.37	35.1	64.9
Weight per m^2 (kg/m^2)	0.50	0.03	0.22	0.19	12.6	86.4

Table 2. Mean yields of sweet potato for each plot type on the raided and control farm presented by total number and total weight per m^2 of exclosure.

Farm	Plot type	Open matched with fence	Fence	Open matched with mesh	Mesh	F df = 3, 8	P
Raided	Number per m^2 ± SE	4.04 ± 0.32	11.52 ± 0.85	6.11 ± 0.82	12.26 ± 0.42	9.71	0.005
	Weight per m^2 (kg/m^2) ± SE	0.13 ± 0.11	0.47 ± 0.05	0.15 ± 0.02	0.50 ± 0.02	10.50	0.004
Control	Number per m^2 ± SE	14.56 ± 1.71	14.19 ± 1.23	32.00 ± 4.62	19.26 ± 3.08	1.964	0.198
	Weight per m^2 (kg/m^2) ± SE	0.81 ± 0.08	0.68 ± 0.06	1.59 ± 0.26	0.94 ± 1.73	1.469	0.294

F values from ANOVA are shown.

Table 3. Differences between farms for overall sweet potato yields for all exclosures (*t*-test, df = 22).

Mean	Control farm	Raided farm	*t*-Test	Sig. value
Number ± SD	180.00 ± 104.09	76.33 ± 37.10	3.250	0.006
Weight (kg) ± SD	9.02 ± 5.566	2.81 ± 1.823	3.671	0.003
Number per m^2 ± SD	20.00 ± 11.565	8.48 ± 4.122	3.250	0.006
Weight per m^2 (kg/m^2) ± SD	1.00 ± 0.619	0.31 ± 0.203	3.671	0.003

Although differences were seen between plot types as a result of raiding, the variation between plots was not great and reflects both the overall small farm size in this area (farms of between 0.5 and 1 ha in size; Priston 2005) and foraging patterns of the monkeys. Although monkeys tend to cause greater damage nearer the forest edge, for farms close to the forest they will venture well into the farm (up to 30 m), splitting up and foraging across the farm (*ibid*).

The damage attributed to monkeys may also be an underestimate owing to their reduced usage of the exclosure plots. Focal farm observations revealed that it was almost a month before monkeys foraged within the fenced plots, despite foraging within the open plot areas and next to the fenced ones (see Priston 2005 for detailed results of crop-raiding behaviour). Thus, total yield loss in the fence only plots are likely to be underestimates. These findings mirror farmers' perceptions of crop-damage which report pigs as a more serious problem for local farmers (Priston 2005). There are few published studies of crop-damage at Indonesian sites by primates but one showed that pig-tailed macaques were responsible for significantly more crop-damage than wild pigs, despite raiding less frequently (Linkie et al. 2007). However, it should be noted that much of data in that study was based on self-reporting by farmers. Rao et al. (2002) demonstrated that in India both wild boar and monkeys caused 50–60% of the total crop-damage overall, with wild boar being one of the major agents of crop-damage. However, their study was based on much larger plots covering a variety of crops and with many more large vertebrate pests. Several African studies have revealed primate raiders to be a greater problem than wild pigs, in most cases Baboons (Newmark et al. 1994; Hill 1997; Naughton Treves 1997, 1998), but in all these sites the variety of vertebrate raiding species is far greater than at this study site, pigs and primates are nonetheless serious raiders.

The differences between plots in the control farm suggest that the exclosures themselves affected the sweet potato yield. Thus, yields in the mesh and fence plots in the raided farm should be slightly greater than observed, and as such damage attributed to large vertebrates should be corrected for this effect. As the open plots on the control farm bore far greater yields than both the fence and mesh plots a shading effect seems most likely. It is also possible that mesh plots suffer from higher humidity. Humidity was not measured, but given that the gauge of the mesh was sufficiently large to enable air flow, and there was no evidence of fungal growth or other indicators of excessively high humidity, it seems unlikely that it affected yield significantly. Insect pest damage could have been higher in the mesh plots because of the absence of bird predators. Visual inspections indicated similar levels of insect damage across both farms, mostly in the form of leaf damage by snails. This was present in all types of plots therefore insect damage is also unlikely to explain these differences.

This paper is the first experimental assessment to specifically calculate off-take by crop-raiding monkeys. Accurate data on the effect on crop yields by primates, together with information on local perceptions, are vital for the design of suitable management strategies. This method of estimating off-take by primates offers a cost-effective, time effective, low labour intensive way to get accurate measurements of crop-damage by a variety of medium to large bodied vertebrates such as primates and some ungulates. This is useful in situations were management strategies are being tested or where issues of compensation are at stake. It should be noted that this method could not be used with very large crop damaging ungulates such as Elephants unless significantly stronger, or electrified, fences could be used.

Whilst this study provides data on the minimum impacts on sweet potato yield by primate damage, it also raises some issues in the use of such methods to assess large vertebrate crop-damage. Furthermore, it highlights potential flaws in exclosure plot studies in terms of underestimating the damage through decreased plant growth. Sample size was small in this study and as such some results are not statistically significant. Further study is warranted to further explore these issues, using more and larger plots, placed earlier in the farms to avoid both a potential shading effect and to allow monkeys to habituate to their presence.

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