FINAL RESEARCH REPORT

Searching for coexistence: prediction, pattern, and perception towards crop feeding long-tailed macaque (*Macaca fascicularis*) on subsistence farm in Padang, West Sumatra, Indonesia.

Fiscal year 2021 - 2022

Team

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1. Introduction

The increasing rate of human activities in natural habitats has facilitated the existence of humans and primates living nearby (Peterson et al. 2010). The close interaction between the two species often leads to high tensions, competing over space and resources. Human encroachment on natural habitats in the form of agriculture expansion, establishment of human housing, and urban infrastructure has decreased habitat quality and quantity for primates. As a response, primates frequently utilize human areas to acquire food, subsequently bringing them into conflict with humans (Linkie et al. 2007; Hill 2017a; Findlay and Hill 2020). Conflicts have been recorded in many regions where primates are native or invasive, not only in developing countries but also increasing in developed countries such as Japan, China, and Taiwan (Tsuji and Ilham 2021). The emerging conflict is fast becoming a severe conservation issue because conflicts are recognized as one of the main threats to primate population survival and represent risks to local human populations (Woodroffe et al. 2005).

Crop consumption or depredation by primates can significantly impact farmers, especially smallholder farmers who depend on agriculture for their subsistence. For example, crop losses caused by primates in Rwanda reach 10-20% of the total household income (Guinness and Taylor 2014). Subsistence farmers in Buton, Sulawesi, suffer losses of up to 70% of their crops from crop-feeding Buton macaques (*Macaca ochreata brunnescens*) (Priston and McLennan 2013). Financial losses incurred by crop-feeding primates have prompted extensive persecution (Hill 2004; Strum 2010). While farmers have used various non-lethal control methods, they are often perceived as ineffective. Farmers are often left to deal with crop damage alone without help from local governments. Consequently, farmers often deal with crop-feeding issues by killing the animals on their farms (Peterson et al. 2010). Intense persecution can be even more severe when species suspected of crop-feeding are threatened with extinction or already suffering from hunting pressure. For example, in Indonesia, around 750 and 1800 individuals of Borneo orangutan are killed annually due to crop-feeding issues (Meijaard et al. 2011), while more than 3000 macaques were captured and killed in retaliation for crop damage they caused (Southwick et al. 1983).

Addressing the negative interaction between humans and primates in the context of crop feeding is an urgent conservation priority, essential for ensuring the long-term coexistence of both species. Therefore, developing an appropriate mitigation strategy to minimize crop losses by primates is necessary. Before doing so, however, we must evaluate the patterns of crop feeding and factor causes primates feed on crops. The expansion of agriculture, linked to human population growth, is significantly associated with deforestation (Scherr and McNeely 2002). Deforestation has decreased available space for primates and destroyed their natural food sources. In response, primates have begun to feed on crops in their surrounding habitats (Priston 2005; Wang et al. 2006; Riley 2007). Simultaneously, human behavior, such as planting and growing crops adjacent to primate habitats, makes cultivated crops available and accessible to them (Lee and Priston 2005). Cultivated foods have become an integral part of their diet for many primates. Although most studies document that primates incorporate cultivated foods into their daily basis, the extent of damage tends to peak during specific periods (Sailer and Robbins 2016; Riley 2007). For instance, Naughton-Treves et al. (1998) and Chaves and Bicca-Marques (2017) have found a positive correlation between crop damage and natural food availability, with crop-feeding by monkeys tending to peak when natural food resources are lacking. In natural habitats, fluctuations in fruit availability were substantial enough to reduce their access to high-quality food resources. However, the presence of cultivated foods can provide alternative food resources to maintain a high-quality diet (McKinney et al. 2015; Hill 2017b). These factors are likely to influence crop consumption by primates. Moreover, studies indicate that primates feed on crops meet their nutritional requirements and metabolic demands (Forthman-Quick and Demment 1988; McLennan and Ganzhorn 2017). For example, cacao that feed by Tonkean macaques (*Macaca tonkeana*) exhibited lower insoluble fiber content and higher carbohydrate energy compared to their wild fruit counterparts (Riley et al. 2013). Similarly, diets of vervet monkeys (*Cercopithecus aethiops*) at Lake Nabugabo, Uganda, revealed distinctions in the relative proportions of macronutrients between wild and cultivated foods with many crops containing higher proportions of carbohydrates and proteins relative to lipids compared to wild foods (Cancelliere et al., 2018). These results suggest that crops are indeed high-quality foods in that they provide a rich source of energy from easily digestible carbohydrates.

Even after extensive years of research and substantial financial investments have been directed towards mitigation efforts, there persists a notable gap in our understanding of the fundamental aspects of human-primates conflicts over crop feeding or damaging. Earlier research have been suggested to evaluate factors influencing the susceptibility of agriculture (Dickman 2010; Fuentes and Hockings 2010; Riley and Priston 2010). This approach is instrumental in identify high-priority farm for conflict intervention and mitigation efforts can be focused toward these vulnerable agriculture fields to minimize crop losses. Most studies have pointed out that the vulnerability of farms to crop feeding involves a combination of factors (Lee and Priston 2005; Mochizuki and Murakami 2011; Baranga et al. 2012). For example, a study documented that agricultural fields near the forest edge were more prone to crop damage by rhesus macaques than those farther from the forest boundary (Koirala et al., 2021). However, Hill (2000) found that the absence of neighboring farms increased crop damage caused by baboons in Uganda. Additionally, Chaves and Bicca-Marques (2017) identified a positive correlation between the extent of crop damage by brown howler (*Alouatta guariba clamitans*) and the abundance of particular crops in the cultivated field. These indicated that the vulnerability of farms to crop damage by primates is influenced by many factors and different species exhibit varying patterns. Despite the existing knowledge on farm vulnerability to crop feeding primates, many gaps remain in this understanding. Since the current knowledge largely comes from studies focusing on very few location and species (Humle 2003; Hill et al. 2002). As human-primates interfaces increase, more primates' species are reported to feed on crops, highlighting the need for site and species specific assessment.

Moreover, mitigation effort can also contribute to the extent of damage caused by primates (Hill 2000; Naughton-Treves and Treves 2005; Wallace and Hill 2012). Researchers have proposed that farms facing high susceptible should enhance their defensive measures, it because the increased efforts can potentially reduce the risk of damage (Lee and Priston 2005). A study by Linkie et al. (2017) found that out of 50 farmers who experienced significant crop damage, only 10% implemented crop protection measures, with more than 90% showing less interest in investing due to perceived ineffectiveness. It is not surprising that individual farmers may be more inclined to invest additional effort in deterring animals from crop feeding only when such efforts have success to reduce crop damage. Amongst various strategies, field guarding is one of the most common mitigation strategies employed by farmers (Riley 2007; Hill and Wallace

2012; Findlay and Hill 2020). This method requires low financial investment but is labor and time consuming (Hill 2005, Lee and Priston 2005). Despite being a favored strategy, the effectiveness of field guarding in preventing crop damage remained uncertain. Earlier studies have noted various factors that may affect the success of field guarding. For example, Wallace (2010) reported that field guarding can become less effective when crop-foraging events involved a small number of individuals monkey. This was attributed to delayed responses by farmers, as they enter the farm in small numbers and often go unnoticed. The effectiveness of guarding also depend on the number of people involved on guarding (Nijman and Nekaris 2010, Strum 2010) as well their activity while in the farm (Hockings 2016, Zak and Riley 2017). However, little is known on how farm characteristic may correlate to the effectiveness of field guarding. Understanding and addressing farm-specific factors can enhance the overall effectiveness of guarding methods in preventing crop feeding by primates.

Crop-feeding primates have declined people's perceptions and attitudes towards them (Knight 2001; Brotcorne 2009). Despite the fact that humans and primates have a long history of coexistence in sharing habitats (Riley and Priston 2010; Fuentes 2013; Radhakrishna 2013), the increase in conflict has disrupted the positive relationship between these two species. Farmers often view primates in agriculture as problematic pests, although the actual extent of damage is often less (Chalise and Johnson 2001; Knight 2003). People's perceptions and attitudes can be influenced by several factors, such as age, gender, ethnicity, level of education, landholding size, period of residency, and religion (Wang et al. 2006; Campbell-Smith et al. 2010). In Bali, local people showed a high tolerance towards macaques despite crop-feeding macaques still being a source of tension (Brotcorne 2009). This positive attitude was determined by the cultural benefits derived from the macaque presence in the temple. In North Sumatra, Muslim farmers tend to be more tolerant towards crop-feeding orangutans if farmers do not feel threatened by the presence of this species (Campbell-Smith et al. 2010). Attitudes also exhibit regional differences; most people living closer to wild areas hold more negative views towards primates (Nijman and Nekaris 2010). However, other studies reveal no relationship (Riley and Priston 2010). In addition, past events can strongly influence perceptions (Naughton-Treves 1997). Perceptions and attitudes can be helpful indicators of how people respond to conflict. If local people attach a negative impression to primates and other wildlife, they will not support conservation; indeed, conservation will work with support from the local community (Riley 2006; Fuentes 2012). For that reasons, understanding of the level of human–primate conflict in regards to crop feeding and the attitude of local farmer is vital to designing effective mitigation strategies and conservation plans.

1.1 Problem statement

Indonesia has experienced significant issues with crop-feeding primates over the past three decades, with the long-tailed macaques (*Macaca fascicularis*) being the most documented to date (Tsuji and Ilham 2021). The substantial damage to crops caused by these macaques has triggered retaliatory killings by farmers, resulting in a significant decrease in their population. The latest IUCN assessment has classified the long-tailed macaque as 'Endangered' (Hansen et al. 2022). Despite the severe consequences, most studies on crop-feeding primates have investigated the aspects of crop loss and people's perceptions. In contrast, no studies have considered the ecological aspect of crop-feeding long-tailed macaques. Understanding the human dimension is not sufficient in itself, but it is essential to integrate with an understanding of the ecological aspect of the monkey species. This study aims to investigate crop-raiding by the long-tailed macaque (hereafter: LTM) in terms of the ecological factors affecting the susceptibility of farms to crop damage, the pattern of their crop feeding, and the attitudes and perceptions of the farmers towards them. Specifically, my study aims to investigate the following questions:

What ecological factors (farm characteristics and patterns of crop feeding LTM) influence the vulnerability of farms to crop damage caused by the LTM and the effectiveness of guarding methods? Through this investigation, I intend to evaluate the following predictions:

(a) Despite the fact that LTM is omnivorous, the susceptibility of crops would significantly vary between crop species. Specifically, I predict that certain crops will be more damaged than others.

(b) The vulnerability of a farm to crop damage by the LTM will vary for each individual farm. I predict that farms located near the forest edge, with a relatively large size and high crop diversity, would experience a higher level of vulnerability than those located elsewhere.

(c) Farms that invest more effort in guarding their crops will experience lower levels of macaque crop feeding. However, the perceived effectiveness of field guarding will also vary between farmers. I predict that the effectiveness of field guarding will decrease for those farms located near the forest edge, with a relatively large size and less presence of people in the farm.

What factors affect macaque feeding on crops? Is crop consumption more advantageous than natural food resources? Through this investigation, I intend to evaluate the following predictions:

(a) Wild fruit and crop availability will show variations throughout the study period, and I predict there will be variations in the utilization of wild and crop foods.

(b) The macaque will feed on crops at any time of the day; however, I predict a temporal pattern will be much higher during morning and evening in response to the time farmers arrive and leave their fields.

(c) The macaque feeds on crops on a daily basis. However, I predict that crop feeding will increase when wild fruits are scarce and when crops are mature, attracted to high availability, nutrient quality, and palatability.

How do farmers perceive crop-feeding long-tailed macaques, their support for the conservation of the macaques, and suggested mitigations?. Through this investigation, I intend to evaluate the following predictions:

(a) The degree of crop damage would be severer in protected sites, and I predict that farmers in protected sites are less likely to tolerate crop damage caused by LTM and have less support for conservation.

(b) Attitudes of coexistence and conservation would not be explained solely by crop loss but also by socio-economic factors such as the source of income, sex, age, and education.

2. Material and Methods

2.1 Study area

The study carried out from 2022 to 2023 in Padang City, West Sumatra, Indonesia. Padang is the capital and largest city of the province of West Sumatra in Indonesia and situated at coordinates 0.9492° S latitude and 100.3543° E longitude along the west coast of Sumatra. Padang City encompasses an area of approximately 695 km2 with a human population of around 1 million individuals (BPS 2022). Approximately 70% of the people in Padang rely primarily on subsistence activities, including farming and fishing. Padang experiences a tropical and slightly seasonal climate, with temperatures ranging from 27°C to 32°C and an average annual rainfall of 2290 mm. The climate is characterized by two distinct seasons: a dry season from February to June and a rainy season from July to late January (BPS 2022). The region is marked by a diverse range of habitats, encompassing rainforests, lowland forests, and swamps. This habitat diversity sustains approximately 4000 plant species, over 80 mammal species, and 370 bird species (Brun et al. 2015). Within the primate order, Padang's forests harbor at least seven primate species, including Sumatran slow loris (*Nycticebus coucang*), Long-tailed macaque (*Macaca fascicularis*), Southern Pig-tailed macaque (*Macaca nemestrina nemestrina*), Silvery lutung (*Trachypithecus auratus*), Black crested langur (*Presbytis melalophos*), Agile Gibbon (*Hylobacthes Agilis*) and Siamang (*Simpalangus Syndactilus*). Over the past century, Padang's forests have undergone a significant but gradual depletion of natural forest cover, primarily attributed to small-scale agriculture, urban infrastructure development, and large-scale rubber (*Hevea brasiliensis*) and palm oil (*Elaeis guineensis*) plantations. An analysis of Landsat TM 8 satellite imagery in 2020 by the Geographic Information System (GIS) team of the Indonesian Conservation Community Warsi revealed a notable reduction in natural forest cover in West Sumatra. The current forest cover in the region stands at only 1.8 million hectares, constituting 44% of the total area. This decline raises concerns about potential repercussions on conservation, biodiversity, climate, water resources, cultural heritage, and ecosystem services (Gursky-Doyen and Supriatna 2010). As per the IUCN Red List in 2023, the Agile Gibbon and Siamang are classified as critically endangered, Sumatran slow loris, Long-tailed macaque, Southern Pig-tailed macaque, Black-crested langur as endangered, and Silvery lutung as vulnerable.

2.2 Study species

The long-tailed macaque (*Macaca fascicularis*) exhibits one of the most extensive geographical distributions among primates. Its natural range spans from the southernmost regions of Bangladesh to the Nicobar Islands, encompassing southern Myanmar, Thailand, Cambodia, southern Laos, Vietnam, Malaysia, and Singapore. Additionally, its distribution extends across the islands of the Philippines and spans Indonesia, covering Sumatra, Borneo, Java, Bali, Lombok, Nusa Tenggara, Flores, and Timor (Umapathy et al. 2003). Long-tailed macaques primarily inhabit low elevations, with their habitat reaching a maximum altitude of 2300 meters (Fooden, 2006). They are commonly observed in various natural settings, including mangroves, swamps, coastal, riverine forests, and secondary forests. Due to rapid landscape anthropization in Indonesia, the proportion of forest edges and the number of disturbed forests are increasing. Consequently, the probability of long-tailed macaque populations living in proximity to human settlements has risen (Gumert et al. 2011). The adaptability of long-tailed macaques to different habitat types is attributed to their capacity to adjust their diet based on resource availability. However, the ongoing conversion of natural habitats into farmland has led to an increasing number of reports identifying the long-tailed macaque as a crop pest (Tsuji and Ilham 2021). The substantial crop damage caused by the long-tailed macaque has triggered retaliatory killings by farmers, resulting in a significant decrease in its population. The latest IUCN assessment has classified the Long-Tailed Macaque as 'Endangered' (Hansen et al. 2022).

3. General methodology and data collected

3.1 Assessing ecological factors determined vulnerability of farm to crop feeding LTM

I employ a mixed methods approach to address the objectives of my research. In the first research objective, I focus on investigating the ecological factors influencing the vulnerability of farms to crop damage by long-tailed macaques in subsistence farms in Padang. To address my research questions, I conducted a field survey and semi-structured interviews involving a total of 200 farms. This approach allowed me to gain insights into the ecological and agricultural contexts related to crop-raiding by long-tailed macaques. The study was carried out in five districts within Padang City, West Sumatra, Indonesia: Lubuk Begalung (LB), Padang Barat (PB), Kuranji (KI), Pauh (PH), and Lubuk Minturun (LM) (refer to Fig. 1). I specifically selected these districts due to the observed increase in crop feeding by long-tailed macaques (Ilham 2022, personal observation). To differentiate the sites, I categorized LB and PB as "unprotected sites" and KI, PH, and LM as "protected sites" because the latter villages are situated near the Bukit Barisan Wildlife Reserve. Unprotected sites are located approximately 8-10 km from Padang City, with elevations ranging from 30 to 200 meters above sea level. The primary vegetation in these areas is a secondary mixed forest dominated by *Moraceae, Theaceae*, and *Arecaceae* (Ilham et al., 2016). Additionally, these sites are surrounded by roads, human settlements, and farmland (Ilham et al. 2017). On the other hand, protected sites are situated around 15-20 km from the city area, with elevations ranging from 300 to 700 meters. This site comprises a secondary mixed forest dominated by *Euphorbiaceae* and *Moraceae* (Ilham 2022, personal observation). The local climate (in terms of temperature and monthly rainfall) of the two sites was not notably different; the maximum temperature ranged from 32.3 - 33.9℃ and the minimum temperature of 23.3–24.0℃, and rainfall of 104–510 mm (BPS 2022).

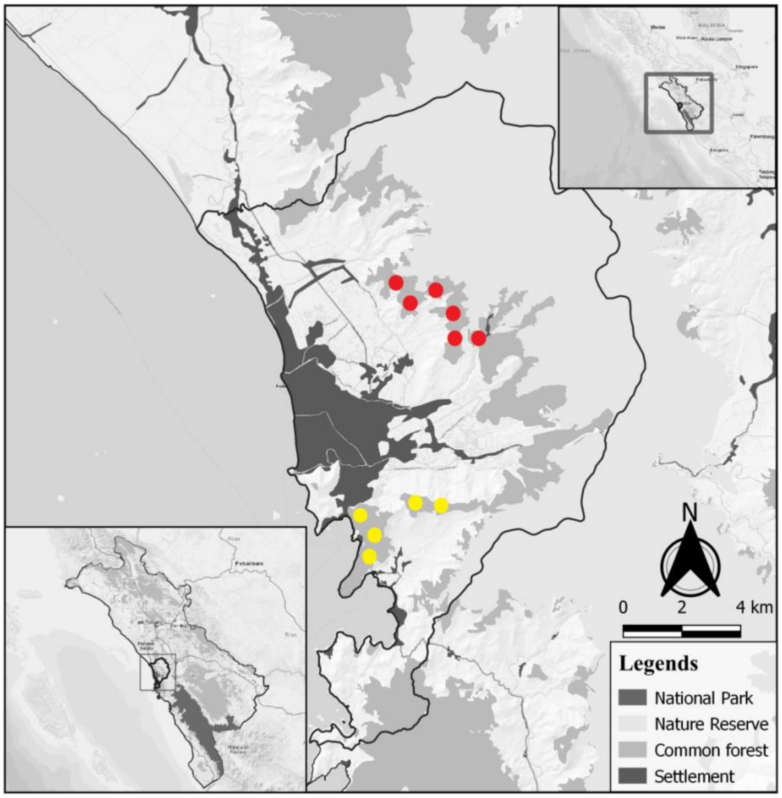


Figure 1. Map of the study area in Padang City, West Sumatra, Indonesia. The red dots indicate the farms of farms surveyed around protected forest sites and yellow dots for farms located in unprotected forest sites.

During the survey, I collected comprehensive information categorized into three key aspects: 1) Farm Characteristics: I recorded information such as farm size, distance from the farm to the forest edge, crop diversity, the number of neighboring farms, characteristics of farm perimeters, and the presence of people on the farm. 2) Crop feeding patterns by the long-tailed macaques: I interviewed the farmers to quantify the patterns of crop feeding they experienced. I collected following information: Frequency of crop feeding incidents Intensity of crop damage Number of individual macaques involved in crop feeding Farmers' enumeration of crops damaged by long-tailed macaques Estimation of crop losses experienced by farmers. 3) Protection efforts used by Farmers: the information includes: Types of protection set in place, and perceived effectiveness. All surveyed farms will be geotagged with coordinates, enabling the validation of data on farm size, distance from the forest edge, and the presence of neighboring farms using Google Earth and GIS (refer to Fig. 2). Furthermore, I conducted on-ground validation to verify data on crop diversity, the presence of people, characteristics of farm perimeters, and the effectiveness of protection efforts.

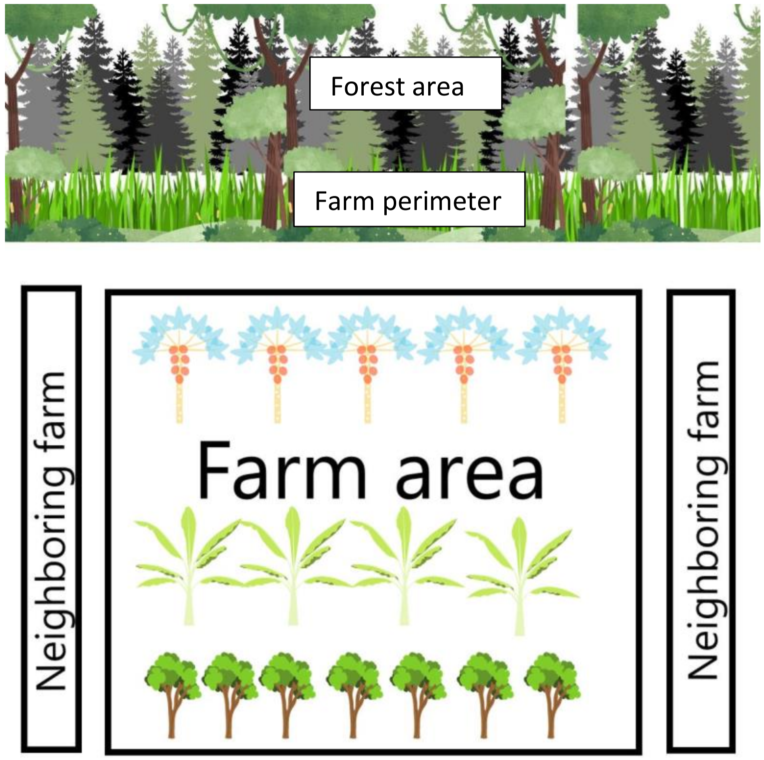


Figure 2. Characteristics of farms surveyed during the study.

3.2 Temporal pattern of crop feeding long-tailed macaques

Second, investigate pattern of crop feeding the LTM in a subsistence farm. First, I established phenology transects to monitor natural food availability. I adjusted the positioning of the line transects based on the sleeping sites of the macaques (Fig 3). Each transect line spans a length of 500 meters, and I subsequently established quadrant plots (50 x 50 m). I monitor the fruit availability of trees consumed by the macaques, with measurements limited to trees possessing a Diameter at Breast Height (DBH) greater than 5cm. I monitored the availability of fruit monthly throughout the study's duration. I assign a score to each tree based on fruit availability: 0 (absent), 1 (1–25% of canopy cover), 2 (26–50%), 3 (51–75%), and 4 (76–100%). I will also assess crop food availability through an evaluation of crop species diversity on the farm, quantifying the number of each species planted, and recorded the fruits availability of each individual crop crops. In addition, I record data on temperature and rainfall patterns.

I use camera traps instead of direct observation to monitor crop feeding incidents. Primatologists increasingly prefer camera traps because they allow researchers to conduct noninvasive observations, eliminating the need to habituate and collect data in different periods and conditions. I deployed a total of 12 camera traps positioned in three zones around the farm area (Fig. 4). Zone 1 is classified as high vulnerability, located approximately 10-30m from the forest edge. Zone 2 is classified as medium vulnerability (31-50m), and Zone 3 is classified as low vulnerability (> 50m). I collect data on crop feeding events, including the frequency of crop feeding, the time of day macaques perform crop feeding, the number of individuals involved, the duration of crop feeding, crops consumed and ignored, and the location of crop feeding incidents.

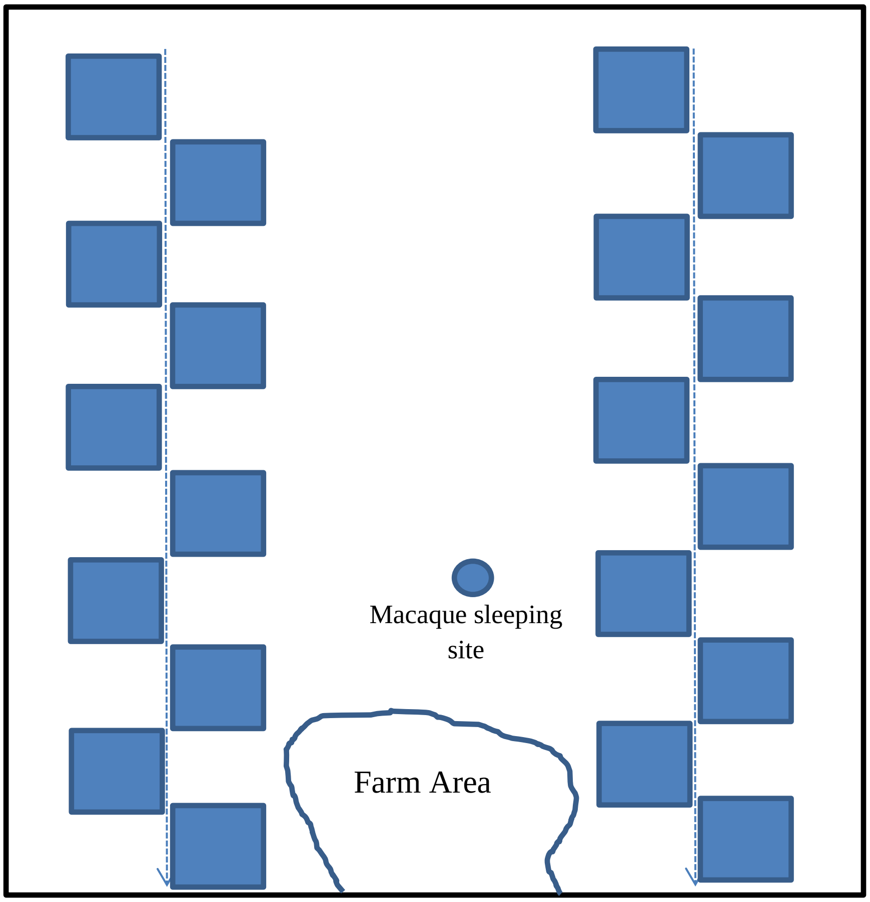


Figure 3. Setting up two phenological transects for monitoring wild food availability of the long-tailed macaque.

I use the ad-libitum method to obtain natural food consumption by the long-tailed macaques. During the study, I also collected fruit samples of natural fruits and crops that are most consumed by the macaques (*n*=5 samples of each) for proximate analysis to determine the nutritional composition of these fruits. The fruits collected will be partitioned into four parts: crude protein, crude fat, crude fiber, and ash.

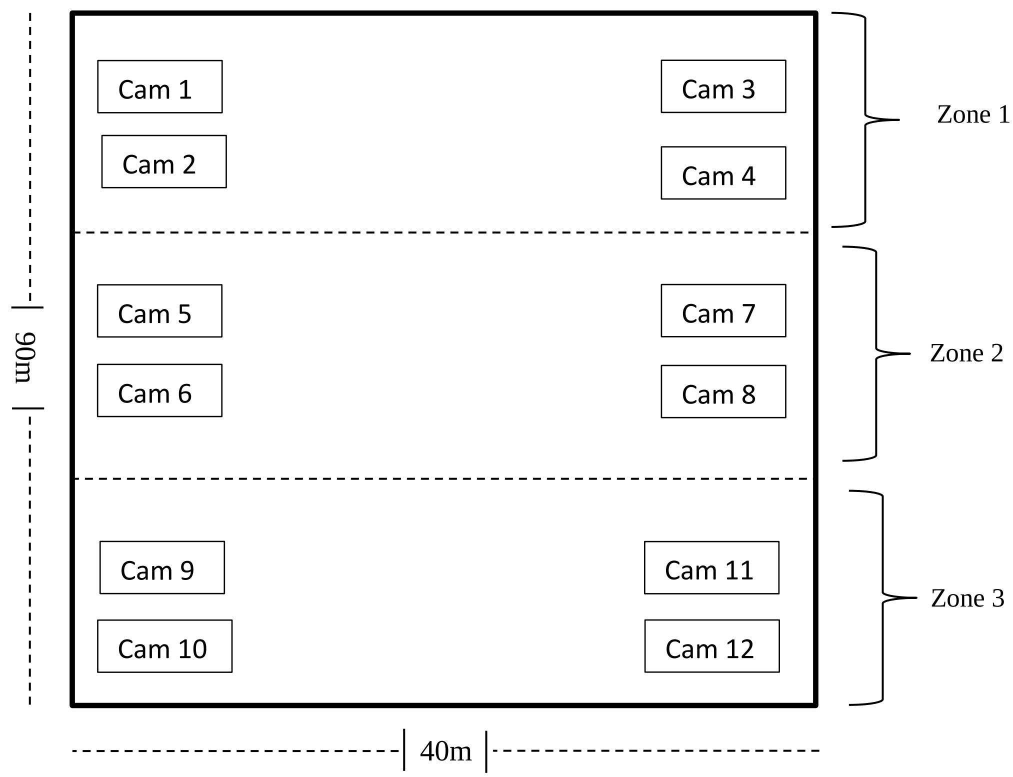


Figure 4. Set up the location of camera traps in a focal farm to observe the crop feeding behavior of the long-tailed macaque.

3.3 Farmers' perception and attitudes towards crop feeding LTM

Third, I explore farmers' perceptions and attitudes toward crop-feeding macaques through a structured questionnaire survey. I am conducting questionnaire interviews with 200 subsistence farmers (refer to Figure 1 for the location of interviewed farmers). The interviews are designed to determine socio-economic characteristics affecting farmers' perceptions toward the coexistence and conservation of the long-tailed macaque by exploring the following: (i) Perception of crop-feeding experience, including patterns, trends, concerned costs, and levels of crop losses. (ii) Perception of the factors driving long-tailed macaques to feed on crops. (iii) Perception of tolerance and conservation towards crop-feeding macaques. (iv) Mitigation solutions suggested. The interviews are anonymous and voluntary; each household is represented by at least one adult individual (≥ 18 years old). Before starting the interview, participants provided their written informed consent to voluntarily participate in this study. They are informed that confidentiality will be guaranteed, and that the interview will, on average, last 15 minutes. Interviews are conducted in Bahasa Indonesia or Minang (local language).

4. Data analysis

4.1 Assessing ecological factors determined vulnerability of farm to crop feeding LTM

Based on the survey, I categorized some variables to improve statistical power. Data categorization can be subjective, so I standardized them by defining specific criteria for each. Farm size refers to the total land area a farm occupies and utilizes for agricultural activities, typically measured in acres or hectares. I categorized farm size as 'big' if the size equals or exceeds 0.76 hectares and 'small' if the farm size is less than 0.76 hectares. Distance from the farm to the forest refers to the measurement or extent of space between the boundaries of a farm and the nearest edge or boundary of a forest. The distance of the farm to the forest is categorized as 'near' if less than 100m and 'far' if more than 100m. Crop diversity refers to the number of crops planted on a farm, and I categorized it as less crop diversity of species planted 'less than 11' and diverse if more than 11 species. The number of neighboring farms is the count of farms in proximity or adjacency to a specific farm, categorized as 'absent = 0' and 'present ≥ 1.' Farm perimeters refer to the characteristics of the farm boundary, which can be composed of shrubs, grasses, or trees. I designated 'open perimeters' if the farm boundary is mostly covered by shrubs or grasses and 'closed perimeters' is mostly covered by trees. I also categorized the number of macaques reported by farmers fed on their crops to be 0-50 as less abundance and exceed 50 as abundance. Last, the presence of people on farms refers to the number of individuals within a farm; I categorized it as 'low' if ≤ 2 persons and 'high' if more than 2 persons.

To gain a general understanding of the differences in farm characteristics in both protected and unprotected forest sites I used the Chi-square test (χ^2). To examine the vulnerability of farms, I employed adaptive epidemiological models developed by Nijman and Nekaris (2010). Initially, I assessed the incidence risk for each crop, calculated using the formula below

$$\text{IR}= \frac{Number\ of\ farms\ were\ macaques\ damaged\ crops\ "a"}{Number\ of\ farms\ \ were\ crops\ "a"\ was\ present}$$

The Incidence Risk (IR) ranges from 0.0 to 1, where a value of 1 indicates high susceptibility, and 0.0 indicates low susceptibility. These models have shown reliability in predicting the vulnerability of crops to feeding or damage by primates. Following this, I determine the Vulnerability of the farm (VF) by summing the IRs for all crops in the field. The VF will be calculated using the formula below:

$$\text{VF} = \sum IR\ (all\ crops\ present\ available\ in\ farms)$$

The total VF index can exceed 1, with a higher VF indicating a greater susceptibility. However, we classified RV into three categories: RV ranged from 1 to 4.05 as low, 4.06 to 6.65 as medium, and over 6.65 as high. In regard to assessing field guarding effectiveness (PE), I divided the total ranking score by farmers by the total number of guarding methods used in each farm area. I then designated that PE scale ranges from 1 to 1.49 (ineffective), 1.5 to 2.49 (partly effective), and ≥ 2.5 (very effective).

Mann-Whitney U test will be used to compare the number of crops damaged, the farm vulnerability index, protection effort, and the perceived effectiveness of field guarding between sites. I then perform Pearson correlation tests to establish the strength and direction of relationships between (1) Incidence Risk and the number of crops planted and (2) Vulnerability of the farm and the number of protection methods used. Further, the Pearson correlation test will be performed to understand the effects of six independent variables (farm size, distance farm to forest edge, crop diversity, number of neighboring farms, characteristic of farm perimeters, and presence of people) that might determine VF and PE. Finally, I used Random Forest (RF) decision trees to assess variables that significantly predicted VF and PE based on interview data. Random Forest classifier comprised 100 decision trees, each with a maximum depth of 10, along with other default hyper-parameters. In a decision tree, nodes terminate when the data within them cannot be further categorized, achieving a state of 'purity.' The purity or impurity of each node is measured using the Gini impurity index formula. The Gini index approaches zero when a subset is pure, containing only a single class. The model guides a subset of data through a decision tree, splitting it at nodes with the objective of minimizing the Gini impurity index. The model's performance will be assessed using standard metrics, including accuracy, recall, and F1 score.

4.2 Temporal pattern of crop feeding long-tailed macaque

The following formula will be used to calculate the fruit availability index (FA Index):

$$FA = \frac{[\sum(pi\ x\ fi)\ ]}{[\ \sum(pi\ x\ 4)]}\ x\ 100$$

Where *pi* is the basal area of the tree (cm^2), and *fi* is the fruiting score of the tree (0–4). I used a t-test in order to compare the differences in monthly fruit index between forest and crop foods, and then I performed one-way ANOVA to assess whether there are significant differences in fruit availability across the study period. I then used the Mann-U test to compare the monthly feeding effort (frequency) of the LTM towards natural fruits and crops. I estimate crop selection using the selection ratio (*Wi*) following Manly et al. (2002):

$$w_i = o_i / \pi_i$$

where, where *oi* is the proportion of each crop *i* with damage by LTM and *πi* is the proportion of available resources in the environment (i.e., the proportion of each crop *i* in each farm). Positive selection (preference) occurs when $Wi > 1$ and negative selection (rejection) when $Wi < 1$. Thus, I classified each crop type according to its selection ratio as low preference when $Wi \leq 0.75$, medium preference when $0.75 < Wi < 1.25$, and high preference when $Wi \geq 1.25$. Additionally, I calculate Manly's standardized selection ratio (*Bi*), for relative comparisons, which ranges from 0 to 1. I use the Spearman correlation (r) to assess the correlation between crop feeding events with natural foods and crop availability. I then employ ANOVA to compare the frequency of crop feeding according to the time of day (morning, afternoon, evening) and vulnerability zone of the farm (high risk, medium risk, and low risk) and their interaction. In then compare the nutritional composition of natural and crop foods consumed by the LTM by using the Mann-U test.

4.3 People's perception and attitudes towards the crop feeding long-tailed macaques

Socioeconomic variables are also categorized to enhance statistical power and the clarity of recommendations. The variables are categorized as follows: Gender: male or female, Age: 'young' (17–40 years) and 'old' (> 40 years), Education: non-educated (never received formal education) and educated (received formal education, including primary education or higher), Main source of income: farming and non-farming, and Farmland ownership: owned or rented. To categorize monthly income levels, we use the average income of people in Padang (2,500,000

IDR/month, equivalent to 165 USD) as a reference (BPS, 2022). Therefore, monthly income is categorized as < 2,500,000 IDR (<165 USD) and ≥ 2,500,000 IDR (≥165 USD). The level of crop losses is also categorized as 0-25% as low, 26-49% as moderate, and ≥ 50% as high losses. These percentages are calculated by dividing estimates of the monthly crop losses by the monthly income reported by farmers, multiplied by 100%. Chi-square (χ^2) tests are used to explore differences between sites in: Socio-economic characteristics, Crop feeding by long-tailed macaques experienced and perceived costs, Perception of the factors causing and protection methods, Attitudes towards coexistence and conservation, and Mitigation solutions suggested. Logistic regression analyses (GLM with a binomial family and logit link function) are performed to determine which predictors significantly affect farmers' perceptions towards the coexistence and conservation of long-tailed macaques. I selected a specific question as the most representative of people's attitudes towards coexistence: 'Do crop-feeding long-tailed macaques and associated damage can be tolerated?' to which farmers could answer 'yes' (1) or 'no' (0). For support for conservation, we used the question, 'Are you willing to support the conservation of long-tailed macaques?' to which farmers could answer 'yes' (1) or 'no' (0). Seven predictors are used, such as age, gender, education, source of income, land ownership, monthly income, and perceived trend of crop-feeding by long-tailed macaques, to determine factors influencing the coexistence and conservation of long-tailed macaques. I perform stepwise backward elimination based on Akaike's information criterion (AIC) to select the best model for the seven predictors. Using the 'aictab' function from the package AICcmodavg, I extract the AIC values and rank the models using the second-order Akaike information criterion (AICc). We consider models with the lowest delta AIC (ΔAICc) as the best models for analysis. I use the likelihood ratio test ('LRT') to evaluate the model fit. Before fitting the models, I systematically check for multicollinearity among dependent variables to eliminate conflicting variables. I use variance inflation factors (VIFs), where VIFs less than two imply the absence of collinearity (Field 2005).

Results 1. Assessing vulnerability of farm to crop feeding LTM

1.1 Farm characteristics and crop feeding LTM experienced

The farms surveyed in both the unprotected and the protected forest sites exhibited numerous similarities in their characteristics: the size of farms ranged from 0.2 ha to 1.3 ha (mean ± SD: 0.6 ± 0.3), with a notable 61% having small-sized farms across study sites. The distances of farms to the forest edge ranged from 4 to 150 m (Mean ± SD: 0.22 ± 0.10 m/farm), with a significant majority (82.5%) situated close to the forest edge, while only 17.5% were positioned farther away from the forest edge. The number of neighboring farms per farm ranged from 1 to 3, with a mean of 1.75. Approximately 74.5% of farms had neighboring farms, while 25.5% did not. Regarding the variety of crops on the farms, a majority (62.5%) planted more than 13 crops species, while 38.5% planted equal to or fewer than 13 crop species. Additionally, among the 200 surveyed farms, 83% were found to have enclosed perimeters, while the remaining 17% had open perimeters. Concerning the presence of people on farms, most farms (61.5%) reported a lower presence, ranging from 1 to 2 individuals. In contrast, 38.5% of farms reported a higher presence of people, with three or more individuals. Across the study area, no significant differences were found in terms of farm size ($\chi^2 = 0.4$, df = 1, $p = 0.835$), farm distance to forest edge ($\chi^2 = 0.3$, df = 1, $p = 0.568$), diversity of crops planted ($\chi^2 = 0.5$, df = 1, $p = 0.456$), types of farm perimeters ($\chi^2 = 0.6$, df = 1, $p = 0.658$) and the presence of people in the surrounding farm ($\chi^2 = 0.2$, df = 1, $p = 0.614$). A significant difference was found in terms of the number of neighboring farms ($\chi^2 = 10.7$, df = 1, $p < 0.001$): there were more farms in the protected area without neighboring farm than those in the unprotected area (**Table. 1**).

Approximately 79% farmers encountered daily crop feeding the macaque (four to more than five times a week), while 15.5% reported monthly (less than ten times per month), and 5% mentioned occasionally (three to four times in a year) occurrences ($\chi^2 = 1.7$, df = 2, $p = 0.423$). The individual macaque involved ranged from 15 to over 100 individuals macaque (mean and SD: 42 ± 21individuals). Nevertheless, majority (56%) of farmers reported less than 50 individuals macaque involved per incident and 44% less than 50 individuals ($\chi^2 = 1.4$, df = 1, $p = 0.704$). Although the frequency of macaques reported feed on crops was similar in the two study sites, the time of LTM perform crop feeding was significantly vary ($\chi^2 = 11.5$, df = 2, $p = 0.003$). In protected site, farmers reported that the LTM feed on crop more frequent in morning and afternoon, while farmers in the unprotected sites reported crop feeding to be most frequent in morning and evening.

Table 1. The differences of farm characteristic and pattern crop feeding LTM reported by farmers in the unprotected and protected forest sites

Variables	Categories	Study area		Chi-square (χ^2)
		Protected	Unprotected	
Farm size	Big (≥ 0.76 ha)	40.00	37.50	$p = 0.835$
	Small (< 0.76 ha)	60.00	62.50	
Distance to forest edge	Far (≥ 100m)	15.83	20.00	$p = 0.568$
	Near (≤ 100m)	84.16	80.00	
Neighboring farm	Absences (“0”)	34.17	65.83	$p < 0.001$
	Presences (≥ “1”)	12.50	87.50	
Diversity of crops planted	Less diverse (≤ 13 species)	41.25	35.50	$p = 0.456$
	More diverse (> 13 species)	58.75	65.50	
Presence of people	High (≥ 2 person)	33.67	41.25	$p = 0.523$
	Low (≤ 2 person)	63.33	58.75	
Type of perimeters	Open (shrub/grass)	14.17	21.25	$p = 0.658$
	Close (trees)	85.83	78.75	
Time of day crop feeding	Morning (06:00 to 10:00)	67.50	62.50	$p = 0.003$
	Afternoon (11:00 to 15:00)	19.17	7.50	
	Evening (16:00 to 18:00)	13.33	30.0	
Frequency	Daily	82.50	75.00	$p = 0.423$
	Weekly	15.00	16.25	
	Monthly	2.50	8.75	
Number of individuals	Abundance (≥ 50)	69.17	61.25	$p = 0.704$
	Less abundance (≤ 50)	30.83	38.75	

1.2 Incidence risk of crops, farm vulnerability and ecological correlates

Across 200 farms surveyed, a total of 27 crop species were recorded being planted by farmers in both sites (**Table. 2**). The number of crops damaged by the macaque did not significantly differ between sites (Mann-Whitney *U*: 4701, $p = 0.805$). In the unprotected site crops damage ranged from 2-14 species with an average 12 species per farm. While in the protected site crops damage ranged from 2-12 species with an average 11 species per farm. Of the crops, banana (94.5%), Jackfruit (94%), papaya (94%), durian (86%) and rambutan (85%) were the most common crops planted by the famers in the unprotected and protected forest site. Nearly all crops grown by farmers in both study sites (unprotected: 85% and protected: 96%) were susceptible to feed by the macaque (**Table 2**).

Table 2. List of crops planted and damage by the LTM across our study site and its incidence risk index

No	Crops species	Scientific names	Number of planted	Number of damaged	Incidence Risk (IR)
1	Durian	*Durio Zhibethinus*	172	150	0.87
2	Papaya	*Carica papaya*	188	160	0.85
3	Jackfruit	*Artocarpus integer*	188	135	0.72
4	Banana	*Musa paradisiaca*	189	123	0.65
5	Cacao	*Theobroma cacao*	146	91	0.62
6	Jengkol	*Pithecellobium jiringa*	143	86	0.60
7	Mango	*Mangifera indica*	143	79	0.55
8	Bitter bean	*Parkia speciosa*	168	88	0.52
9	Manggo (Kueni)	*Mangifera odorata*	153	58	0.38
10	Mangosteen	*Garcinia mangostana*	67	25	0.37
11	Maize	*Zea mays*	23	8	0.35
12	Rambutan	*Nephelium lappaceum*	170	59	0.35
13	Water guava	*Syzygium aqueum*	128	34	0.27
14	Coconut	*Cocos nucifera*	93	24	0.26
15	Jamaican cherry	*Muntingia calabura*	12	2	0.17
16	Langsat	*Lansium domesticum*	55	9	0.16
17	Melinjo	*Gnetum gnemon*	59	8	0.14
18	Avocado	*Persea americana*	8	1	0.13
19	Coffee	*Coffea arabica*	17	2	0.12
20	Egg plant	*Solanum melongena*	90	9	0.10
21	Sweet potato	*Ipomoea batatas*	30	3	0.10
22	Chili	*Capsicum annuum*	101	10	0.10
23	Cassava	*Manihot esculenta*	139	13	0.09
24	Sugar cane	*Saccharum officinarum*	70	6	0.09
25	Watermelon	*Citrullus lanatus*	27	2	0.07
26	Nutmeg	*Myristica fragrans*	59	3	0.05
27	Peanut	*Arachis hypogaea*	24	1	0.04

Nevertheless, incidence risks (IR) of individual crops were significantly higher for durian (0.87), papaya (0.85), jackfruit (0.72%), banana (0.65%), and cacao (0.62%). Conversely, lower incident risks were recorded for watermelon, nutmeg, and peanut. Notably, incident risks of crops (IR) were correlated with the number of farms planting specific crops (Pearson: $r = 0.75$, df = 24, $p < 0.001$) indicating that crops with higher incident risks are likely to be more abundant and widespread. Given to that, vulnerability of farm to crop feeding did not significant differ between the sites (Mann-Whitney U: 4383, $p = 0.299$). The median VF for farm the unprotected site is 0.61 (range 2.65-7.11) whereas the VF for farm in the protected site is 0.59 (range 2.47-7.22). As results, more than half of the farms (53.3%) were categorized high susceptible, 38% as medium and only 8.5% categorized as low susceptible (**Supplementary Table 1**). Amongst seven ecological factors assessed, vulnerability of farm appears to be related to farm size ($r = 0.75$, df = 198, $p > 0.001$; Fig. 2a), distance to forest edge ($r = -0.63$, df = 198, $p > 0.001$; Fig. 2b), number of crops ($r = 0.51$, df = 198, $p > 0.001$; Fig. 2c) and number of macaques ($r = 0.20$, df = 198, $p > 0.001$; Fig. 2d). While vulnerability were uncorrelated with the presences of neighboring farm ($r = -0.45$, df = 198, $p = 0.523$; Fig. 2e), types of perimeters ($r = 0.09$, df = 198, $p = 0.200$; Fig. 2f), and frequency of crop feeding the macaque ($r = -0.04$, df = 198, $p = 0.533$; Fig. 2d).

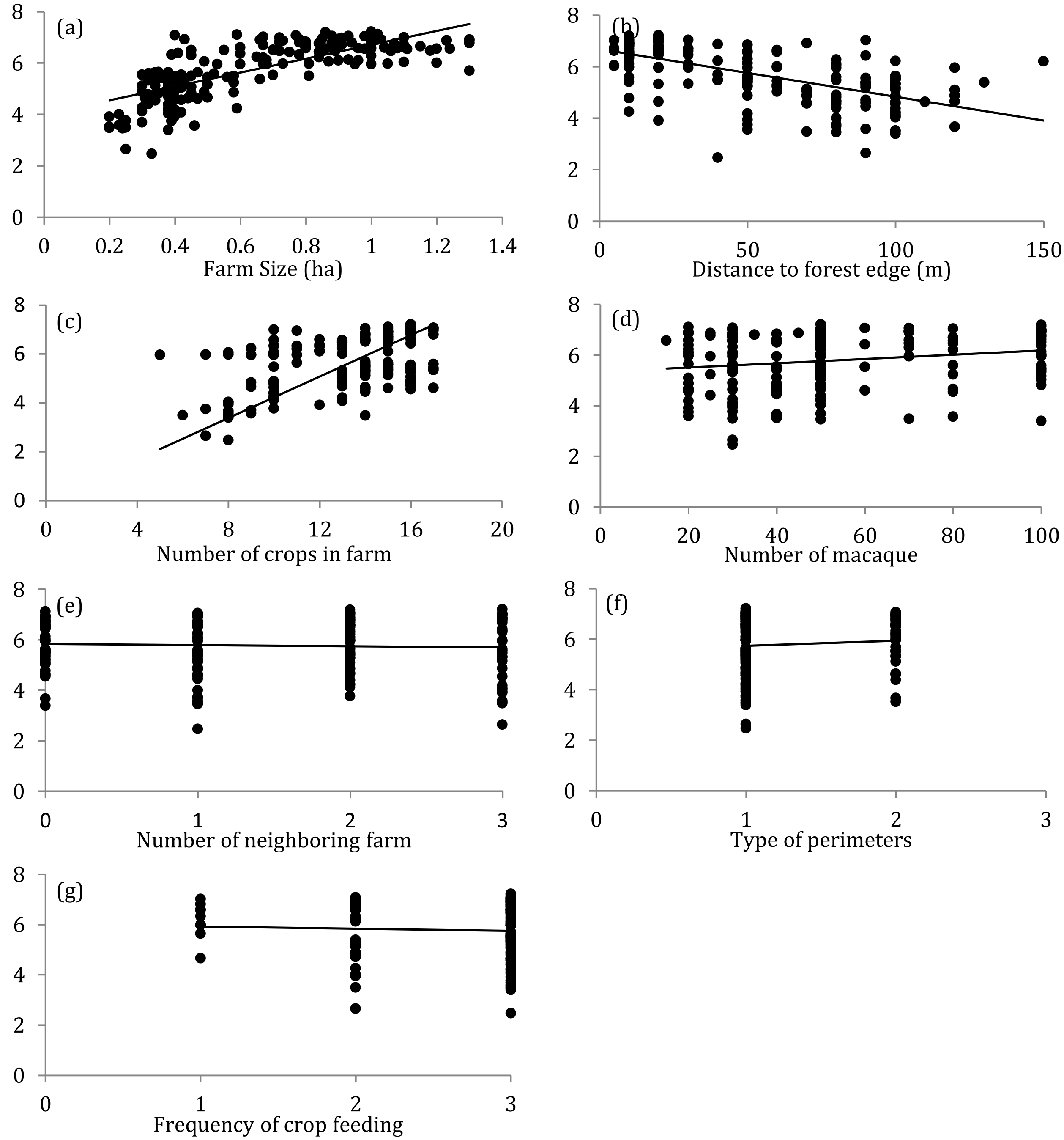


Figure 2. The relationship between vulnerability of farm (VF) with (a) farm size, (b) distance to forest edge, (c) number of crops, (d) number of macaques, (e) number of neighboring farm, (f) types of perimeter, (g) frequency of crop feeding. Line shows the correlation trend

1.3 Protection efforts, the effectiveness and its ecological correlates

Farmers have used a combination of traditional methods to minimize the crop loss around their farmland (Table 3). In total there were 10 different used in which chasing (100%), human guarding (94.5%), covering fruits (80%), and dogs guarding (78%), were most commonly used, respectively. The number of guarding (chasing, using dogs and human) used per farms did significantly differ between in the unprotected and protected sites (Mann-Whitney *U*: 5962**,** $p < 0.05$) and the use of guarding was negatively correlated with higher vulnerability of farm to crop feeding the macaque ($r = -0.14$, $df = 198$, $p = 0.04$).

Table 3. List of crop protection methods used by farmers to reduce crop damage

Methods	Study sites		Total	%
	Unprotected	Protected		
Shouting	80	120	200	100.00
Human guarding	71	118	189	94.50
covering fruits	65	96	161	80.50
Dog Guarding	61	95	156	78.00
Plat metal on the tree	60	95	155	77.50
Fire crackers	60	79	139	69.50
Suspending cans	61	63	124	62.00
Wood Fence	25	48	73	36.50
Scarecrow	21	45	66	33.00
Electric fence	0	3	3	1.50

The effectiveness of these intervention was evaluated among farmers ($n = 200$) across the study sites. Overall, majority of farmers (61.5%) perceived that guarding was ineffective, while 38.5% considered it to be partly effective and no farmers deemed field guarding 100% effective at deterring crop-feeding LTM. The median PE of field guarding for farmer in the unprotected site is 1.00 (range 1.00-2.33) whereas the PE for farm in the protected site is 1.33 (range 1.00-2.33) and the differences did not significant (Mann-Whitney *U*: 6073, $p = 0.056$). Amongst eight ecological factors assessed, field guarding effectiveness (PE) appears to be related to farm size ($r = -0.45$, df = 198, $p < 0.001$; Fig 3a), distance to forest edge ($r = -0.55$, df = 198, $p < 0.001$; Fig. 3b), the presence of people in farm ($r = 0.28$, df = 198, $p < 0.001$; Fig. 3c) and number of macaques $r = -0.14$, df = 198, $p = 0.045$; Fig. 3d). Inversely, PE of guarding were uncorrelated with the presence of neighboring farm ($r = -0.01$, df = 198, $p = 0.801$; Fig. 3e), number of crops ($r = -0.08$, df = 198, $p = 0.229$; Fig. 3f), types of perimeters ($r = -0.04$, df = 198, $p = 0.519$; Fig. 3g) and frequency crop feeding ($r = 0.05$, df = 198, $p = 0.443$; Fig. 3h).

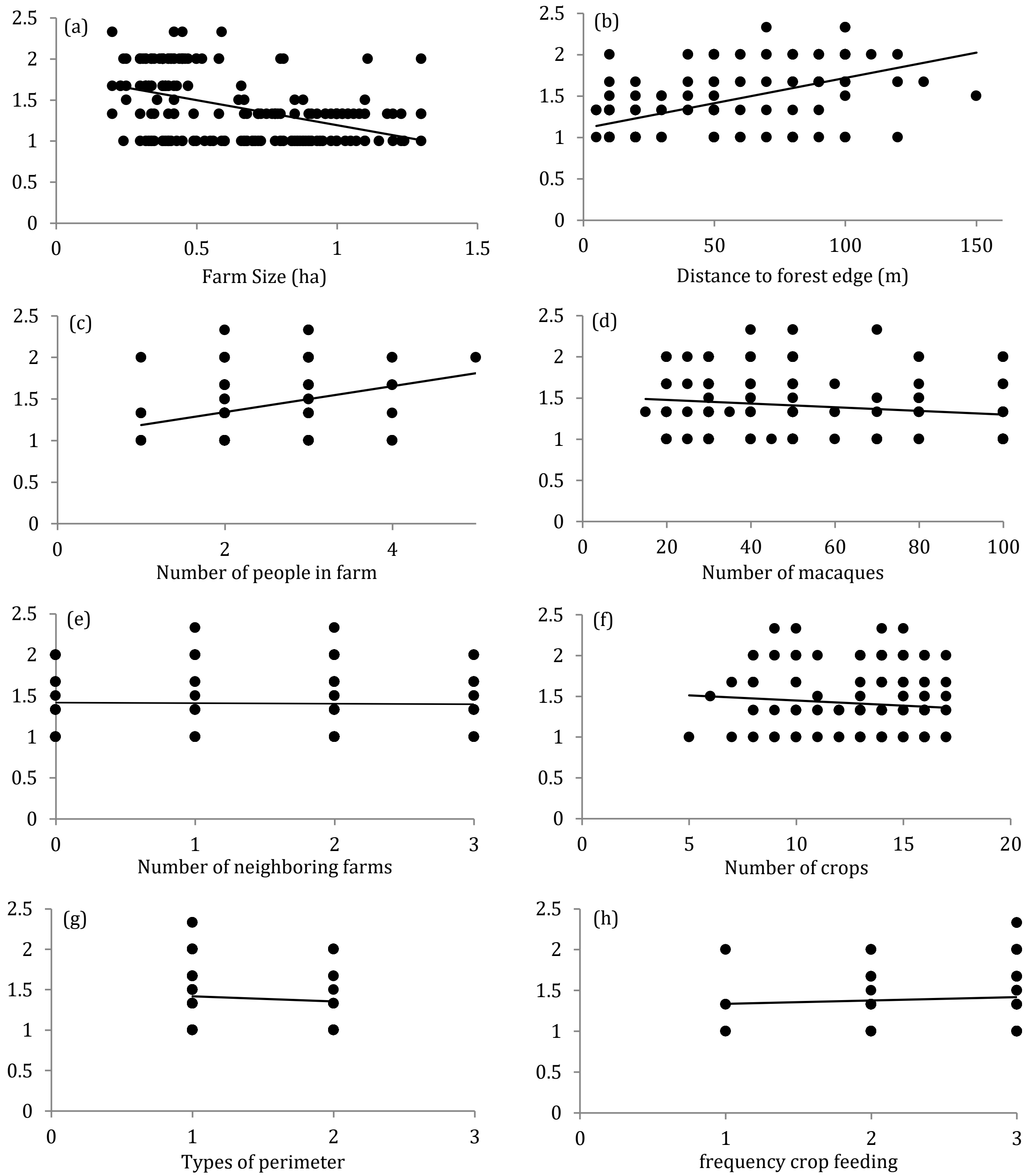


Figure 3. The relationship between field guarding effectiveness (EF) with (a) farm size, (b) distance to forest edge, (c) presences people in farm, (d) number of macaques, (e) number of neighboring farms, (f) number of crops, (g) types of perimeter, (h) frequency of crop feeding. Line shows the correlation trend

1.4 Predictive important factors using Random Forest analysis

The random forest correctly identified 83 farms as highly vulnerable, with the model/classifier achieved 76.9% correct predictions and confidence interval ranging from 67.8% to 84.4%. While random forest correctly identified 62 farms as medium vulnerable, and the model achieved 83.8% correct predictions with confidence interval ranged from 73.4% to 91.3%. Additionally, the model also correctly identified 8 farms as low vulnerable but the model achieved 44.4% correct predictions, with a confidence interval from 21.5% to 69.2% (**Supplementary table 3a**). Amongst the eight variables examined to predict farm vulnerability, the random forest model indicated that farm size, distance to forest edge, and the number of crops were most important factor affecting farm vulnerability (**Fig. 4a**).

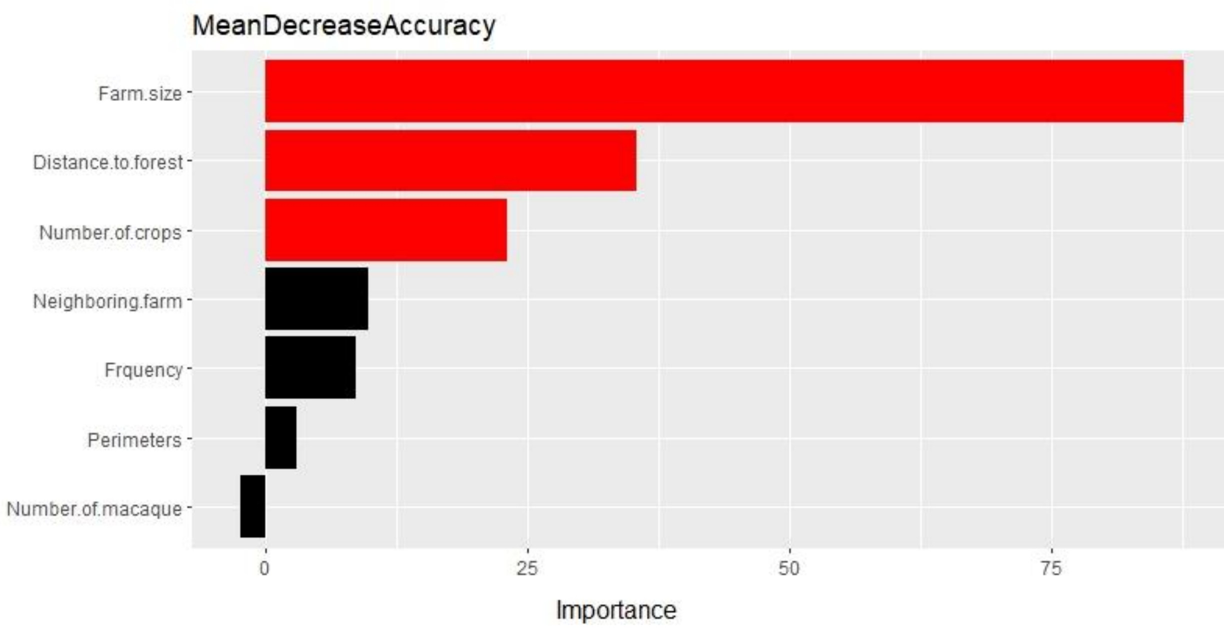


Figure 4a. The importance ecological factors determined vulnerability of farm

Overall, accuracies of the model were 0.98, precision 0.75, and F1 score 0.85. The mean decrease accuracy for farm size was 21.6, and mean GINI decrease was 32.1. For distance to forest, the corresponding values of mean decrease accuracy 8.62 and mean GINI decrease 8.5, respectively. While for number of crops, the mean decrease accuracy 6.4 and mean GINI decrease 5.9 (**Table 4a**).

Table 4. Mean decrease accuracy and Gini index of most factors determined (a) vulnerability of farm and (b) field guarding effectiveness. Bold indicated variables were most important.

(a)	Variables	High	Low	Medium	MeanDecreaseAccuracy	MeanDecreaseGini
	Farm.size	**19.15098**	**6.218881**	**18.99337**	**21.6545199**	**32.14309955**
	Distance.to.forest	**7.735282**	**-1.23204**	**7.065149**	**8.623911362**	**8.540476585**
	Number.of.crops	**1.259824**	**8.196164**	**2.322587**	**6.460018734**	**5.936662699**
	Frequency	4.793028	1.037061	-0.81156	2.801930439	3.466124309
	Neighboring.farm	-1.68762	0.072961	3.337125	2.028227737	1.983067996
	Perimeters	0.748386	2.322854	-0.40264	1.174521301	2.297108339
	Number.of.macaque	-2.58481	-2.13134	1.296847	-0.854842035	1.846660039
(b)	Variables	Effective	Partly effective	Ineffective	MeanDecreaseAccuracy	MeanDecreaseGini
	Farm.size	**0**	**8.322663**	**16.59756053**	**17.48812059**	**19.19873467**
	Distance.to.forest	**0**	**5.765963**	**14.81730804**	**13.5109313**	**12.94092729**
	Number.of.people	0	3.470586	2.416180106	4.182313742	5.78752444
	Frequency	0	-0.27840	1.239678657	0.718588753	6.275372649
	Number.of.macaque	0	-1.16491	2.506930327	0.699187204	4.410127558
	Perimeters	0	-2.06923	0.773798484	-1.403722132	4.283170362
	Number.of.crops	0	0.811459	-4.25472478	-2.770576745	3.805710721
	Neighboring.farm	0	-3.011234	-2.24674528	-4.434724395	3.267852767

Concerning the effectiveness of active guarding, the random forest correctly identified 91 cases as not effective with the model/classifier achieved 74% correct predictions and confidence interval ranging from 65.3% to 81.5%. While, the random forest correctly identified 65 cases as less effective, with the model/classifier achieved 84% correct predictions and the confidence interval ranging from 74.4% to 91.7% (**Supplementary Table 3b**). Among eight ecological variables examined, the random forest predictive model revealed that the effectiveness of field guarding was predominantly predicted by farm size and distance to the forest edge (**Fig. 4b**). The model exhibited high performance with accuracy (0.85), precision (0.79), and an F1 score (0.80). Regarding feature importance, the mean decrease in accuracy and GINI index reduction for farm size approximately 14.6 and 22.4. For distance to forest edge, the corresponding values were approximately 17.1 and 47.9, respectively (**Table 4b**).

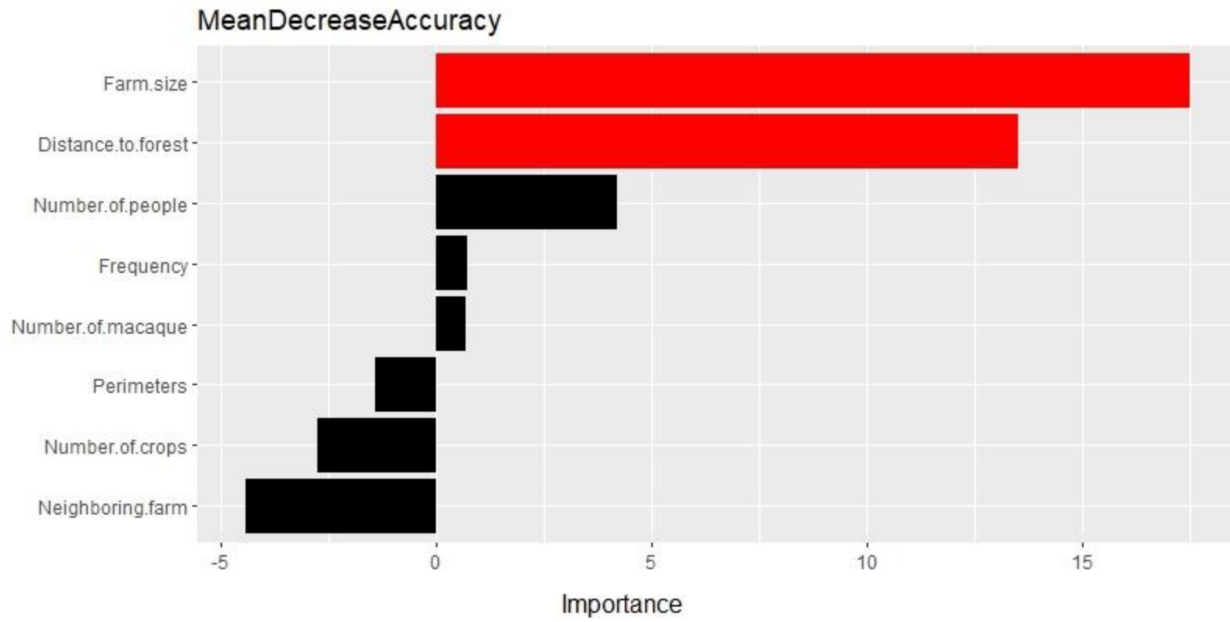


Figure 4b. The importance of ecological factors determined effectiveness of field guarding methods

Result 2. Temporal Pattern of crop feeding LTM in a subsistence farm

2.1 Wild fruits and crops availability

A total of 13 crop species (n = 133 individuals) and 25 wild fruits species (n = 250) were monitored for phenology survey. Fruits index showed that young fruits (YF) and mature fruits (MF) of both wild and crops foods varied throughout the study period. The period of young and mature fruit ‘‘abundance’’ was from October to December (Fig. 5). However there was a significant difference in terms of overall fruits availability between crops and wild fruits across the month: April (Chi-square: $\chi^2 = 17.14$, $df = 3$, $P = 0.001$), May ($\chi^2 = 16.69$, $df = 3$, $P = 0.002$), June ($\chi^2 = 13.31$, $df = 3$, $P < 0.001$), July ($\chi^2 = 16.30$, $df = 3$, $P = 0.001$), August ($\chi^2 = 13.57$, $df = 3$, $P = 0.002$), September ($\chi^2 = 9.10$, $df = 3$, $P = 0.027$), October ($\chi^2 = 11.60$, $df = 3$, $P < 0.001$), November ($\chi^2 = 18.10$, $df = 3$, $P < 0.001$), December $\chi^2 = 20.1$, $df = 3$, $P < 0.001$).

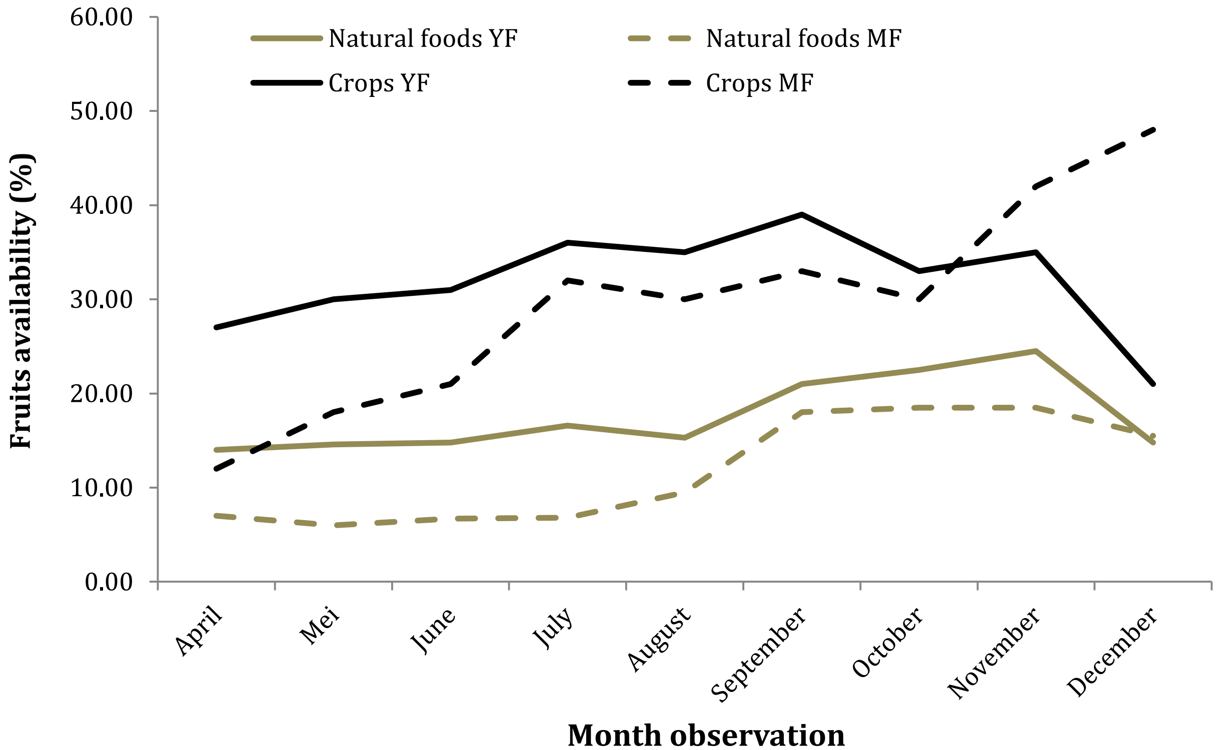


Figure 5. Monthly fruits availability index between crops and wild foods during the study period

2.2 Frequency feeding on crops and wild foods

During the study period, the macaques consumed both natural and crop foods. The macaques consume a total of 13 crops species and 25 wild fruit species. The number of consumed food species and dietary diversity differed by month. The monthly diversity index was 3.99 ± 0.19, ranging from 3.68 to 4.36. There were significant differences in the feeding frequency of each food types (crops and wild foods) across the month (Fig. 6). The long-tailed macaques significantly higher consume fruits from crops than wild foods: April (Mann-Whitney U: 5073, p = 0.046), May (Mann-Whitney U: 4473, p = 0.026), June (Mann-Whitney U: 5743, p = 0.036), July (Mann-Whitney U: 4473, p = 0.005), August (Mann-Whitney U: 7413, p < 0.001), September (Mann-Whitney U: 7067, p < 0.001), October (Mann-Whitney U: 6311, p < 0.001), November (Mann-Whitney U: 8473, p < 0.001), December (Mann-Whitney U: 8653, p < 0.001).

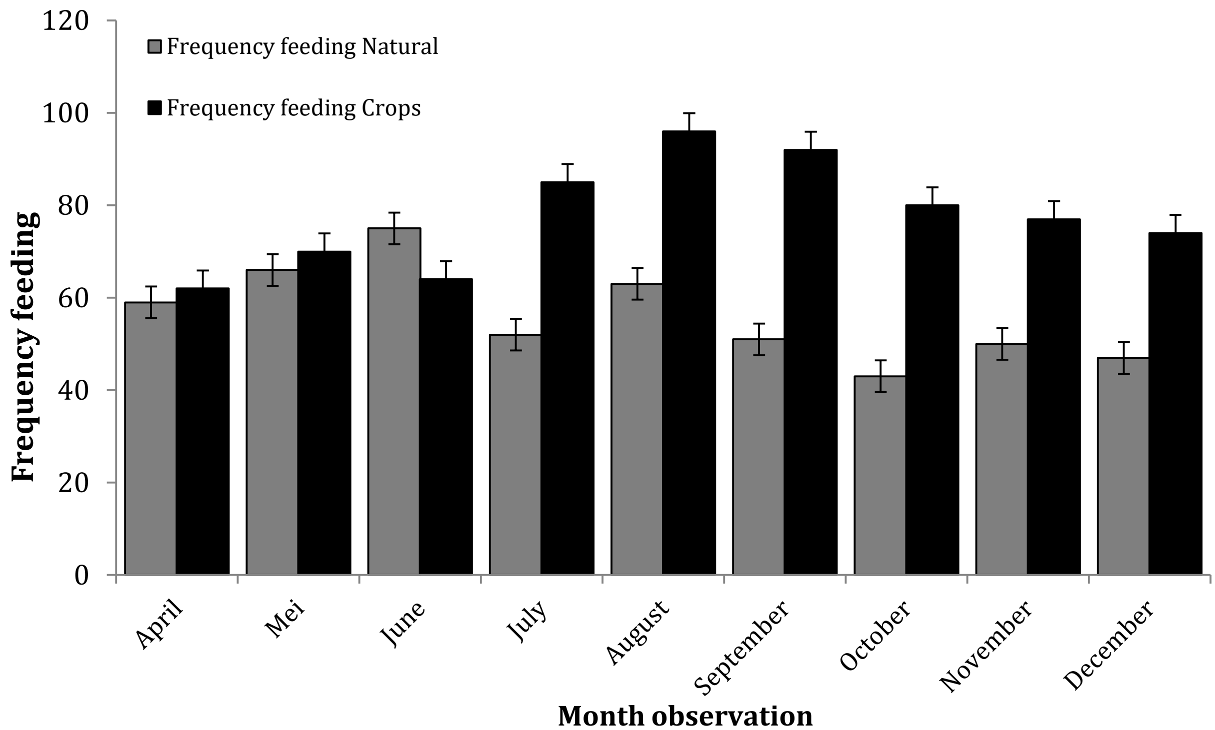


Figure 6. Monthly variation of the long-tailed macaque feed on crops and wild foods during the study period.

2.3 Time of day

The macaques generally entered the field and performed crop feeding significantly higher in the morning than afternoon and Evening. More specifically, crop feeding peaks from 07:00 to 08:00 ((Fig. 7). The time crop feeding activity of the macaque did not significantly vary across the month: April (Kruskal-Wallis H= 14, df = 3, P = 0.001), May (H = 19, df = 3, P = 0.002), June (H = 13, df = 3, P < 0.001), July (H = 13, df = 3, P = 0.001), August (H = 17, df = 3, P = 0.002), September (H = 10, df = 3, P = 0.027), October (H = 16, df = 3, P < 0.001), November (H = 15, df = 3, P < 0.001), December (H = 21, df = 3, P < 0.001).

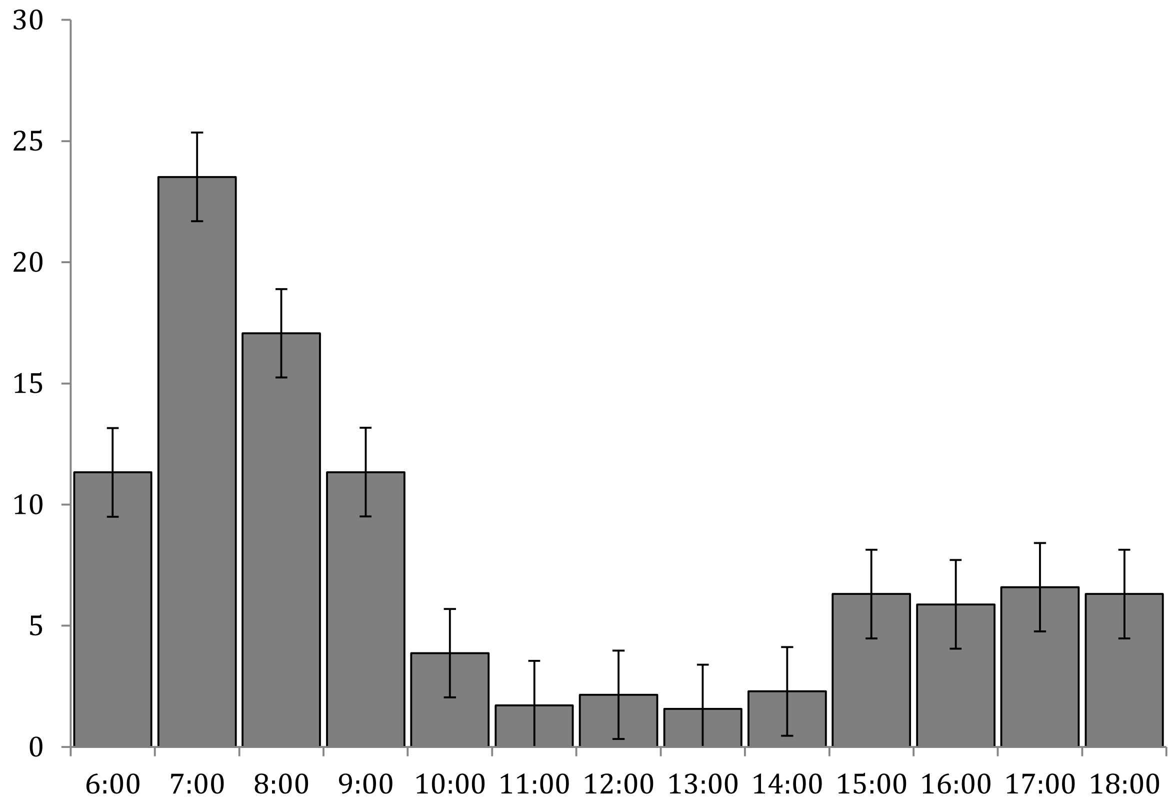


Figure 7. Temporal crop patterns of the long-tailed macaques during the study

Results 3. People perception and attitudes towards crops feeding LTM

3.1 Socio-economic profile of farmers

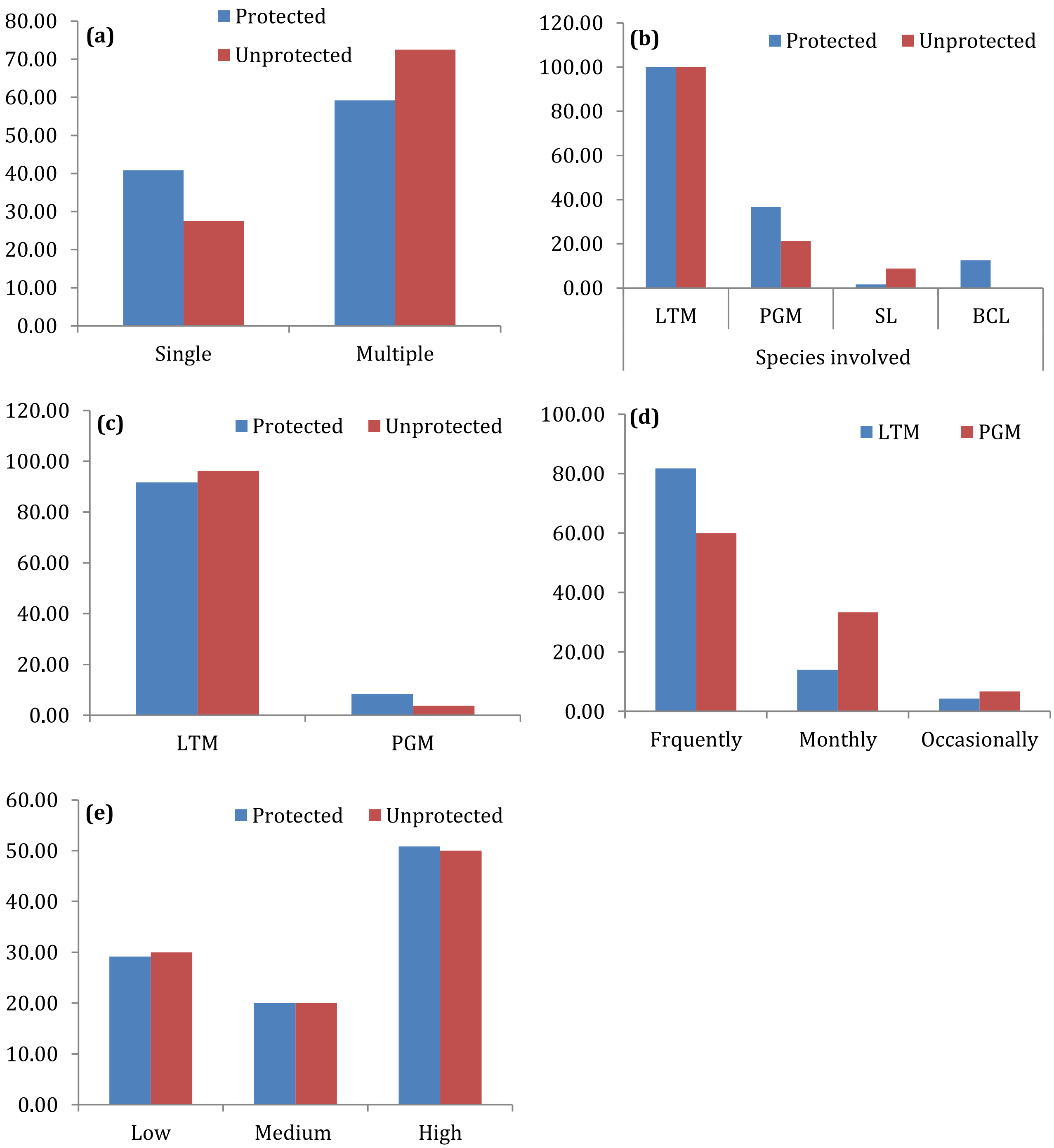
Of the 200 farmers interviewed (**Table 1**), males comprised 91% of the total farmers in the unprotected sites and 88% in the protected sites. The farmers' ages ranged from 18 to 75 (mean and SD: 50.8 ± 24.0). In the unprotected sites, older individuals (> 40 years old) made up 83% of all interviewed farmers, while corresponding value in the protected sites was 91%. There were no significant differences in the proportions of gender (χ^2 = 0.68, df = 1, p = 0.420) and age group (χ^2 = 3.00, df = 1, p = 0.081) of farmers interviewed between sites. There was a significant difference in education level (χ^2 = 26.50, df = 1, p < 0.001), i.e., farmers in unprotected sites (68.3%) were likely more educated than protected sites (31.2%). More than eighty percent (80.5%) of farmers relied entirely on subsistence agriculture for their income. While the remaining (19.5%) included farming as a sideline income, with their main income generated from government employees, labor, fishermen, personal vendors, and other occupations. Between sites, the income sources of farmers were significantly varied (χ^2 = 14.30, df = 1, p < 0.001). A greater number of farmers in protected sites depend on farming activity alone (89.0%), whereas many farmers in unprotected sites rely on other sources of income (33.0%). There was also significant difference in term of duration of respondents being a farmers between sites (χ^2 = 16.89, df = 1, p < 0.001). There more farmers in protected site spend more than 20 years being farmers than those in the unprotected site. The monthly income of farmers interviewed ranged from 800,000 (53 USD) to 6,000,000 IDR/month (400 USD) (mean and SD: 3,000,000 ± 926,000 IDR). Approximately 65.0% of farmers claimed monthly incomes higher than ≥ 2,500,000 IDR/month (≥ 165 USD) while 35.0% were less than 2,500,000 IDR/month (< 165 USD). Overall, the monthly income of the farmers did not significantly differ between sites (χ^2 = 0.80, df = 1, p = 0.364). There were more farmers have income equal or higher than 2,500,000 IDR/month (protected: 67.5% and unprotected: 61.2%). In regards to land owned, there were also no differences in the status of land used by farmers in both sites (χ^2 = 2.70, df = 1, p = 0.092). Most of them owned their farmland for farming purposes (protected: 97.6% and unprotected: 91.3%).

Table 1. The differences of socio-economic characteristic between farmers in unprotected and protected forest sites

Variables	Categories	Location		Chi-square test		
		Protected	Unprotected	χ^2	df	p
Sex	Female	12.5	8.8	0.68	1	0.42
	Male	87.5	91.2			
Age	Old	90.8	82.5	3.04	1	0.081
	Young	9.2	17.5			
Education	Educated	31.7	68.3	26.5	1	< 0.0001
	Non-educated	68.8	31.2			
Source of income	Farming	89.2	67.5	14.3	1	< 0.0001
	Non-farming	10.8	32.5			
Duration being farmers	Less than 20 years	30.8	61.25	16.8	1	<0.001
	More than 20 years	69.17	38.75			
Land owned	Rented	3.3	8.8	2.7	1	0.092
	Owned	96.7	91.3			
Monthly income	< 2.500.000 IDR (< 165 USD)	67.5	61.2	0.82	1	0.364
	≥ 2.500.000 IDR (≥ 165 USD)	32.5	38.8			

3.2 Crop feeding experienced and cost concerned

While all farmers (100%) experienced crop feeding primates, majority (64.5%) encountered crop feeding with multiple primate species, while 35.5% with a single species (Fig. 1a). The percentage of farmers experienced and these differences did not vary between sites (χ^2 = 3.16, df = 1, p = 0.075). In protected sites, three primate's species were identified as crop feeders, in which all farmers (100%) reported issues with long-tailed macaques. Other species mentioned included pig-tailed macaques (36.6%), black-crested langurs (12.5%), and silvery lutungs (1.6%). Similar reports were noted in unprotected sites: whereas all farmers (100%) reported problem with long-tailed macaque, followed by pig-tailed macaques (20%) and silvery langurs (8.7%). No crop feeding by black-crested langurs was reported in this site (Fig 1b). There was no difference was found in terms of species causing more damage between study sites (χ^2 = 1.99, df = 1, p = 0.319). Most farmers in both sites considered the long-tailed macaques to be the most problematic compared to pig-tailed macaques, while black-crested langurs and silvery lutungs were not perceived as destructive crop feeders (Fig. 1c). A large percentage (80%) of farmers reported that crop feeding macaques occurs frequently (five to seven times a week), 15% monthly (five to ten times per month), and only 5.0% occasionally (Fig. 1d). This perception was common across sites (χ^2 = 2.94, df = 2, p = 0.228). A large number of farmers from protected (85.0%) and unprotected sites (71.0%) were likely concerned about economic impact (Fig. 1e). The crop losses ranged from 11% to 250%, with a mean of 46.7% (± 36.5%). Individual level losses did not significantly differ between sites (χ^2 = 0.17, df = 1, p = 0.991). At the time of the interview, a significant number in both protected (50.8%) and unprotected (50.0%) sites experienced high losses, reducing over half of their income (Fig. 1e).


(a)
Protected
Unprotected
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Single
Multiple
(b)
Protected
Unprotected
120.00
100.00
80.00
60.00
40.00
20.00
0.00
LTM
PGM
SL
BCL
Species involved
(c)
Protected
Unprotected
120.00
100.00
80.00
60.00
40.00
20.00
0.00
LTM
PGM
(d)
LTM
PGM
100.00
80.00
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40.00
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Frquently
Monthly
Occasionally
(e)
Protected
Unprotected
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Low
Medium
High

3.3 Factor influencing farmers' attitudes towards coexistences and conservation

Over half (59.5%) of farmers expressed that they were not able to accept crop damage caused by the LTM. While others farmers (40.5%) expressed they could tolerate but wished crop damage could be reduced. The attitudes of tolerance towards crop feeding LTM did not significantly differ between sites (χ^2 =3.0, df = 1, p = 0.08). Model selection based on delta AIC revealed that a best model was one containing sex, age, education, duration being farmers, main source of income, land status, income, and species involved in crop feeding as factors (**Table 3a**). The results of the logistic regression analysis showed that human-macaque coexistence was strongly affected by duration as farmers and species involved in crop feeding as factors (**Table 4a**), with those farmers who have spent more than 20 years in farming activity were likely tolerate to crop feeding macaques than others (β = 3.01 [SE 0.50], p < 0.001). While, those farmers encountered with single were also more tolerate to crop damage caused by macaque than those had problem with multiple macaques (β = 1.9 [SE 0.43], p < 0.001). The chi-square test indicated that the experience factor predicting the attitude of coexistence fits the data well (Likelihood Ratio Test = 88, df = 1, p < 0.001).

Table 3. Model characteristic and selection used stepwise backward elimination based on Akaike's information criterion (AIC) for (a) coexistences and (b) conservation. Bold indicated the best model based on the lowest Delta AIC value.

Model Selection		K	AICc	Delta AICc
Models	***(a) Willingness of coexistences***			
1	**Sex+Age+Education+Duration+Mainsource+Landstatus+Income+Species**	**8**	**247.48**	**0**
2	**Sex+Age+Education+Duration+Mainsource+Landstatus+Income**	7	248.31	0.82
3	**Sex+Age+Education+Duration+Mainsource+Landstatus**	6	252.72	5.24
4	**Sex+Age+Education+Duration+Mainsource**	5	260.92	13.44
5	**Sex+Age+Education+Duration**	4	262.96	15.48
6	**Sex+Age+Education**	3	265.01	17.53
7	**Sex+Age**	2	266.5	19.02
	(b) Support for conservation			
1	**Sex+Age+Education+Duration+Mainsource+Landstatus+Income+Species**	**8**	**240.13**	**0**
2	**Sex+Age+Education+Duration+Mainsource+Landstatus+Income**	7	242.19	2.05
3	**Sex+Age+Education+Duration+Mainsource+Landstatus**	6	243.94	3.8
4	**Sex+Age+Education+Duration+Mainsource**	5	244.27	4.13
5	**Sex+Age+Education+Duration**	4	245.02	4.88
6	**Sex+Age+Education**	3	246.06	5.93
7	**Sex+Age**	2	246.92	6.79

In terms of conservation, more than half of farmers (54.7%) willing to conserve the LTM, and around 45.2% were not. No significant difference was found in terms of conservation support of the macaque between study sites ($\chi^2 = 0.27$, df = 1, $p = 0.594$). Model selection based on delta AIC indicated that a best model was one containing sex, age, education, duration being farmers, main source of income, land status, income, and species involved in crop feeding as factors (**Table 3b**). Logistic regression analysis found that age, duration being farmers and number of species involved in crop feeding significantly affected attitudes toward conservation (**Table 4b**). More specifically, young farmers were less likely to support conservation than old farmers (β = -1.458 [SE 0.62], $p = 0.01$). Those farmers who have spent more than 20 years in farming activity were likely support conserving the macaques (β = 3.07 [SE 0.50], $p < 0.001$). Further, those farmers encountered with single were also more likely to conserve the macaque than those had problem with multiple macaques (β = 1.45 [SE 0.43], $p < 0.001$). The chi-square test indicated that the experience factor predicting the attitude of coexistence fits the data well (Likelihood Ratio Test = 93, df = 1, $p < 0.001$).

Table 4. Summarize the result logistic regression model showing significant factors that influencing farmers' attitude towards (a) coexistence, and (b) conservation of crop feeding long-tailed macaques in Padang West Sumatra. Bold and asterisks indicates significances ($^{**}p < 0.001$, $^{*}p < 0.05$).

Fixed factors	*B*	*SE*	Z	*p*
(a) Coexistence				
Intercept	-3.705	0.848	-4.371	< 0.001
Sex (Male)	0.078	0.668	0.118	0.906
Age (Young)	-0.536	0.622	-0.861	0.389
Education (Primary)	0.295	0.560	0.527	0.598
Education (Secondary)	0.663	0.779	0.851	0.395
Education (University)	0.294	1.130	0.260	0.795
Duration (More than 20 yr)	**3.018**	**0.504**	**5.984**	**< 0.001****
Main source (Others)	0.463	0.508	0.912	0.362
Land status (Rented)	-16.956	31.50	-0.018	0.985
Income (less than 2.5jt)	-0.395	0.501	-0.787	0.431
Species (Single)	**1.998**	**0.431**	**4.635**	**< 0.001****
(b) Conservation				
Intercept	-2.792	0.790	-3.494	< 0.001
Sex (Male)	0.4230	0.653	0.648	0.517
Age (Young)	**-1.485**	**0.622**	**-2.387**	**< 0.05****
Education (Primary)	0.563	0.579	0.972	0.331
Education (Secondary)	1.451	0.776	1.870	0.061
Education (University)	0.414	1.117	0.371	0.710
Duration (More than 20 yr)	**3.079**	**0.468**	**6.573**	**< 0.001****
Main source (Others)	0.676	0.527	1.282	0.199
Land status (Rented)	-1.586	1.087	-1.459	0.144
Income (less than 2.5jt)	0.164	0.508	-0.329	0.742
Species (Single)	**1.458**	**0.438**	**3.330**	**< 0.001****

6. Discussion

To the best of our knowledge, this research represents the first attempt to assess vulnerability of farm to crop feeding long-tailed macaque (LTM). Recognized as a problematic species in agricultural landscapes throughout its distribution range, the extensive crop feeding by long-tailed macaques can have direct implications for farmers' livelihoods consequently its conservation support. Thus, understanding the factors influencing susceptibility of farm to crop damage by LTM is crucial steps toward formulating or improving the effective mitigation measures. Our results revealed that all farms surveyed were experienced with crop damage by the LTM on daily basis. As consequences crop damage by the LTM is fast becoming major problems for the farmers and have exacerbated conflict situation. The macaque have been recorded to feed on a number of crops species in farm, however some crops were more susceptible than others. Notably, we found that durian, papaya, jackfruit and banana were the most crops damaged by the macaque. These fruit crops predominantly grown by farmer in our study area, makes them abundant and easily available. Our result suggests that the likelihood of incidents (IR) for these crops were likely to be affected by its abundance. While all farms experienced crop damage by long-tailed macaques (LTM), the degree of susceptibility varied among the surveyed farms. Our findings revealed that farms with larger sizes, proximity to the forest, and a greater diversity of crops were most at risk of crop damage by LTM. Our finding is supported by earlier studies which documented that level of damage to a crop is a function of its availability (Naughton-Treves et al. 1998; Hill 2000). For instances, Marchal and Hill (2009) observed that Jackfruit, jengkol, durian and bitter bean to be most vulnerable crops damage macaques in North Sumatra as they are highly available in the farm. Naughton-Treves (1998) also documented the same pattern for Baboon in Uganda which actively selected Banana attributed to its availability and abundant.

Furthermore, in this study, we recorded that farmers used different combinations of traditional methods to protect their crops against macaques. A majority of the farmers employed active guarding through chasing, dogs guarding, combined with human guarding. Similarly to other studies, guarding is one of the most common mitigation strategies used by crop farmers. These methods are often perceived by farmers as highly effective in reducing crop damage by wildlife (Arlet and Molleman 2010, Mackenzie and Ahabyona 2012). Indeed, our result shown that farmers put greater effort in field guarding (i.e number of guarding used) was negatively correlated to the risk of farm from crop feeding the macaque. Event though, many farmers perceived these method as ineffective and did not reduce crop damage. Our results revealed that the effectiveness of field guarding was determined by farm size and distance to the forest edge. One possible explanation for this phenomenon is that large farms often have extensive edges or borders that interface with natural habitats where macaques may reside, making it challenging to monitor and allowing macaques to access crops in unguarded areas. Similarly, farms situated close to forests are more likely to decrease the detectability of macaques entering the crop fields. This may be true since our results show a low presence of humans in the field. When there are fewer people, there may be a decrease in deterrent measures, monitoring, and rapid response, leading to an increased vulnerability of crops to damage by macaques. Our predictions are in line with some previous studies that considered that farm characteristics may limit the success of field guarding. For instance, Findlay and Hill (2020) found that farmers managing large agricultural fields often failed to prevent crop feeding by vervet monkeys. This was attributed to delayed responses by farmers, as they enter the farm in small numbers and often go unnoticed. Likewise, Wallace and Hill (2012) reported that guarding seems less effective for farms near forest boundaries. This is because such circumstances reduce the likelihood of primates being detected by farmers.

Understanding temporal patterns and choice in crop raiding provides information on how to manage and reduced crop damage by the macaque. As a result presented here we suggest that crop feeding was a function of the availability of crops which attractive to the macaque. Some crops are more damaged than others. Cultivated foods have become an integral part of their diet for many primates. Although most studies document that primates incorporate cultivated foods into their daily basis, the extent of damage tends to peak during specific periods (Sailer and Robbins 2016; Riley 2007). For instance, Naughton-Treves et al. (1998) and Chaves and Bicca-Marques (2017) have found a positive correlation between crop damage and natural food availability, with crop-feeding by monkeys tending to peak when natural food resources are lacking. In natural habitats, fluctuations in fruit availability were substantial enough to reduce their access to high-quality food resources. However, the presence of cultivated foods can provide alternative food resources to maintain a high-quality diet (McKinney et al. 2015; Hill 2017b). These factors are likely to influence crop consumption by macaques in our study site.

Crop losses can significantly impact attitudes of tolerance toward foraging animals and, thus, their conservation support. In our study, there was a no difference in attitudes of tolerance between farmers in protected and unprotected sites. In many cases, crop damage can promote negative attitudes, which lead to an attribution of killing the macaques. However, we noted an interesting finding in perceptions about conservation support of the LTM. Many farmers in both sites expressed their support for protecting the LTM and other primates as well (Fig. 4b). Most studies on primates conflict due to crop feeding documented that farmer who experienced this problem is less interested in conservation (Mukeka et al. 2019; Kifle 2021). Our result, however, corroborates with Riley and Priston (2010) and Chaves and Bicca-Marquez (2016), which revealed that certain socio-economic factors, were important in predicting farmers' attitudes towards conservation macaques. In our study, factor such as age and duration being as farmers as well as their experienced with single crop feeding species were the most important factors predicting farmers' perception towards conservation macaques. Our findings mirror Campbell-Smith et al. (2010), who found that age, especially older individuals more favorable in supporting conservation due to their higher connection with nature which can reinforce their positive attitudes towards primates. Similarly, farmers' experienced formal educations were much more interested in supporting conversation of crop feeding primates than non-educated farmers. This could be connected to a greater awareness of wildlife and environmental thought at schools. However, it can also be associated with other personal features such as sensibility, empathy, and culture (Riley 2007; Waters et al. 2019; Barbhuiya et al. 2022).

Conclusion

This study shed the light factors influencing farms become susceptible to crop damage by the long-tailed macaque, pattern crop feeding the macaque and perception towards them. Our findings suggest that the susceptibility of farms could be minimized by reducing crop diversity which palatable to macaque and or diversifying crops to include those that are less attractive to the macaque but important for the farmers. We also encourage farmers to avoid cultivating near to the forest edge to reduce the risk of crop damage. While field guarding interventions assessed were largely perceived to be ineffective. We believe that future research should focus on how field guarding techniques used by farmers can be more effective in reducing macaque crop feeding. This could be training farmer properly use field guarding to improve its effectiveness for instance encourage them to be regularly patrol their farms. All farmers in our study site did not learn about crop protection in school or from the government, which causing them to be not able to protect their crops adequately. In addition it could be incorporate low-tech methods to enhance monitoring and early detection of crop feeding macaque.

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Documentation

A. Field work

B. Public awareness campaign

C. Discuss with local stakeholder regarding long-tailed macaque in Gunung Padang