Population survey and human-macaque interactions in moor macaque (*Macaca maura*) in Sulawesi island, Indonesia.

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Awarded a PSGB/Ardith Eudey Grant 2019

Introduction

The moor macaque (*Macaca maura*) is an endemic, endangered species of South Sulawesi, Indonesia, whose population is declining (Supriatna et al., 2008). The population size, geographic distribution, ecology and behaviour of this species are little unknown (for notable exceptions see, e.g.: Okamoto et al., 2000; Riley et al., 2014; Morrow et al., 2019; Albani et al., 2020). The last study on the population structure of moor macaques was published 20 years ago (Okamoto et al., 2000). Such lack of data makes it very difficult to design effective conservation strategies to protect moor macaques from extinction. South Sulawesi is one of the most populated areas in Indonesia, with its capital Makassar being the 4th largest city of Indonesia. The dramatic increase in human population, together with logging, hunting, mining, agricultural and commercial development, constitutes a crucial threat to biodiversity conservation in Sulawesi (Kelley, 2018). Deforestation has significantly increased in the last few years (Phalan et al., 2013), forcing wildlife to either live in relict patches of pristine habitat or in human-affected environment. Therefore, moor macaques face a high extinction risk and effective strategies to protect this species and its habitat are urgently needed.

In the last decade, the geographical range of moor macaques has become mostly restricted to karst areas (Albani et al., 2020), because these areas are less accessible to human activities. Part of the moor macaque range is currently protected by the Bantimurung-Bulusaraung National Park (BBNP), founded in 2004 and 43,750 ha large. However, very little research has been done on the macaque population structure in the BBNP (Morrow et al. 2019; Albani et al., 2020). Therefore, it is not known if the BBNP represents an effective 'barrier' to protect the moor macaque and whether it hosts a viable population of macaques. Furthermore, large areas inhabited by moor macaques, according to IUCN (Supriatna et al., 2008) are outside of the BBNP, where data on the status of the macaque population and the effect of the human activity are scarce/absent.

In this project, I aimed to run a large-scale survey in South Sulawesi to (1) determine the geographic distribution of moor macaques and (2) estimate their population size and structure. Furthermore, I aimed to (3) analyse the effect of human activity on the macaque population.

Methods

I selected areas to be surveyed based on: 1) the geographic distribution of moor macaques according to the IUCN (Supriatna et al., 2008); 2) the presence of suitable habitats

for the macaques; 3) interviews with the local community about the presence/absence of macaques.

In the areas selected for the survey, I used the line transect method to estimate presence/absence of the macaques, their geographic distribution and demography (Butynski, 1990; Plumptre & Reynolds, 1994; Harcourt, 1995; Worman & Chapman, 2006). Moreover, I recorded the presence and type of signs of human activity (e.g. garbage, logging, or mining). In each selected area, I positioned a series of 1000m long transects, trying to cover the maximum part of the area. Each transect was walked twice, on two consecutive days, between 9:00 and 15:00 with a maximum speed of 1km/hr. During the line transects I recorded GPS coordinates every time I detected a macaque. If the macaque was not on the transect, I calculated the perpendicular distance between the line transect and the monkey using a Laser View Finder. The same procedure was used to estimate the presence and density of human activity in each area. Human activity was defined according to a series of non-mutually exclusive categories: presence of humans, presence of animals related to humans (i.e. cows and dogs), presence of temporary human activity (camp, fire, garbage/waste disposal, mining, and construction), absence of forest (agricultural plots, clear cutting, logging) and presence of traps (i.e. wire-loop traps) (see Figure 2). I used the GPS device to keep line transects correctly orientated from start to end. When transect fragments included topographical undulation of steeply elevated inclines, declines and gorges, marked stakes were used to keep accurate distance and orientation measurements (Alldredge et al., 2007).

I started my survey in the areas outside of the BBNP (see Figure 1). Between November 28th and March 20th I collected data at seven different locations, walking a total of 29 transects and 57 km. In March, before I was able to survey the areas inside the National Park, I had to interrupt the study due to the Covid-19 pandemic. Thus, I could not survey the complete area of the *Macaca maura* geographic distribution, as initially planned.

The population size of moor macaques was estimated using Wildlife Density and Distance software, and Google EARTH. Moreover, the effect of the human activity on the macaque population was analysed with a generalized linear mixed model (GLMM) with the glmmTMB package (version 1.0.1; Brooks et al, 2017) in R (R Core Team, version 3.5.0). In the model, I assessed whether the density of the macaques was affected by (1) number of humans in the area, (2) number of pet/farm animals (i.e. cows, dogs), (3) size of the area with temporary human activities (i.e. camp, fire, garbage), (4) size of the open areas (i.e. areas that could not be crossed by a monkey using the canopy) due to logging or farming, (5) number of traps (i.e. loop-wire trap). Finally, I entered transect identity as a random factor in the GLMM. Continuous predictor variables were z-transformed, and no convergence issues were detected.

Figure 1. Map of Sulawesi and the area inhabited by Macaca maura **in South Sulawesi (enlarged).**

Results

My data showed an estimated a global density of 0.254 individual/ha. The full model significantly differed from the null model (GLMM: χ^2 = 12.632, df = 1, p = 0.0271). As expected, the density of macaques was higher in densely forested areas than in areas containing open spaces with no trees (Table 1). However, the density of macaques was also higher the more pet/farm animals in the area. The other variables entered in the model had no significant effect on estimated macaque density.

Discussion

The data collected before the Covid-19 pandemic forced me to interrupt the study provide new evidence that the density of *Macaca maura* is low outside the National Park. The global density estimated during this research is very similar to the minimum estimate provided in the last survey (Supriatna et al., 1992): 0.25 individual/ha. It is possible that the number of macaques in the National Park is greater than the density I estimated outside the BBNP. However, my preliminary data support the view that the moor macaque is endangered. Moreover, it is likely that the macaque population is decreasing, as predicted in the previous survey (Supriatna et al., 1992). In the last 30 years, forest cover has been dramatically reduced in South Sulawesi, due to logging and other human activities (Phalan, 2013). Some of the areas I surveyed in this study are far away from one another and not connected by any ecological corridor. Thus, the possibility for macaques to move across these areas is low or risky (e.g. risk of road crossing). As a result, the populations of moor macaques are likely to be fragmented, which significantly increases the extinction risk for this species, even if the overall estimated number of macaques left in the wild was similar to what was reported in the previous survey.

Moreover, we found that macaque density was higher in areas with a high number of pet/farm animals (a proxy of intensity of human activity). It is possible that macaques prefer to use relatively flat areas, which are also usually preferred by farmers and shepherds. However, this result also indicates that macaques are often in close proximity to humans, likely because they are forced to do so due to increased human activity and reduced pristine habitat. This scenario increases the risk of human-macaque conflict (e.g. due to crop-raiding; Riley & Priston, 2010) and represents a significant threat for the protection of moor macaques. Sulawesi Island lies at the centre of the Wallacea biodiversity hotspot and the forests inhabited by moor macaques also host a large number of endemic and endangered species, especially butterflies, other insects and birds. Therefore, urgent conservation measures are needed to save the forests of Sulawesi and its endangered species. These measures should include, for example, extended protection of areas where moor macaques live, conservation projects involving local communities to develop and run projects that could help the local economy with ecologically sustainable activities, and education projects in schools to increase awareness of conservation issues in future generations.

Future work

As soon as it is safe and I am allowed to resume working in Sulawesi, I plan to survey a larger number of areas, including areas within the National Park. I will then use these data to complete the survey and analyse global density of moor macaques. With more data, I will also be able to more accurately assess the effect of different human activities on the density of the macaques, which will help to develop more specific conservation projects involving local communities and focusing on the protection of the forest and of the endemic species inhabiting the area. Finally, more research on the behaviour of this threatened and little known species should be done to increase our knowledge of this species and implement more effective conservation measures.

Acknowledgments

I would like to express my gratitude to Dr. Amici, Dr. Majolo, and especially to Professor Oka and Dr. Maulany for their help during my time in Sulawesi . Finally, I am very grateful to all the local people from South Sulawesi that helped me during the transects.

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	Estimate	SE	2.5% CI	97.5% CI	LRT	df	P
Intercept	2.65	0.305	2.054	3.249	-	-	-
Human presence	0.51	0.308	-0.098	1.109	2.637	1	0.104
Pet/farm animal presence	0.71	0.292	0.139	1.282	5.651	1	**0.017**
Temporary human activity	-0.26	0.286	-0.821	0.300	0.821	1	0.365
Presence of open area	-0.67	0.309	-1.279	-0.067	4.558	1	**0.033**
Trap presence	-0.65	0.389	-1.417	0.107	2.768	1	0.096

Table 1. Results of the GLMM model, including estimates, standard errors (SE), confidence intervals (CIs), likelihood ratio tests (LRT), degrees of freedom (df) and P values.

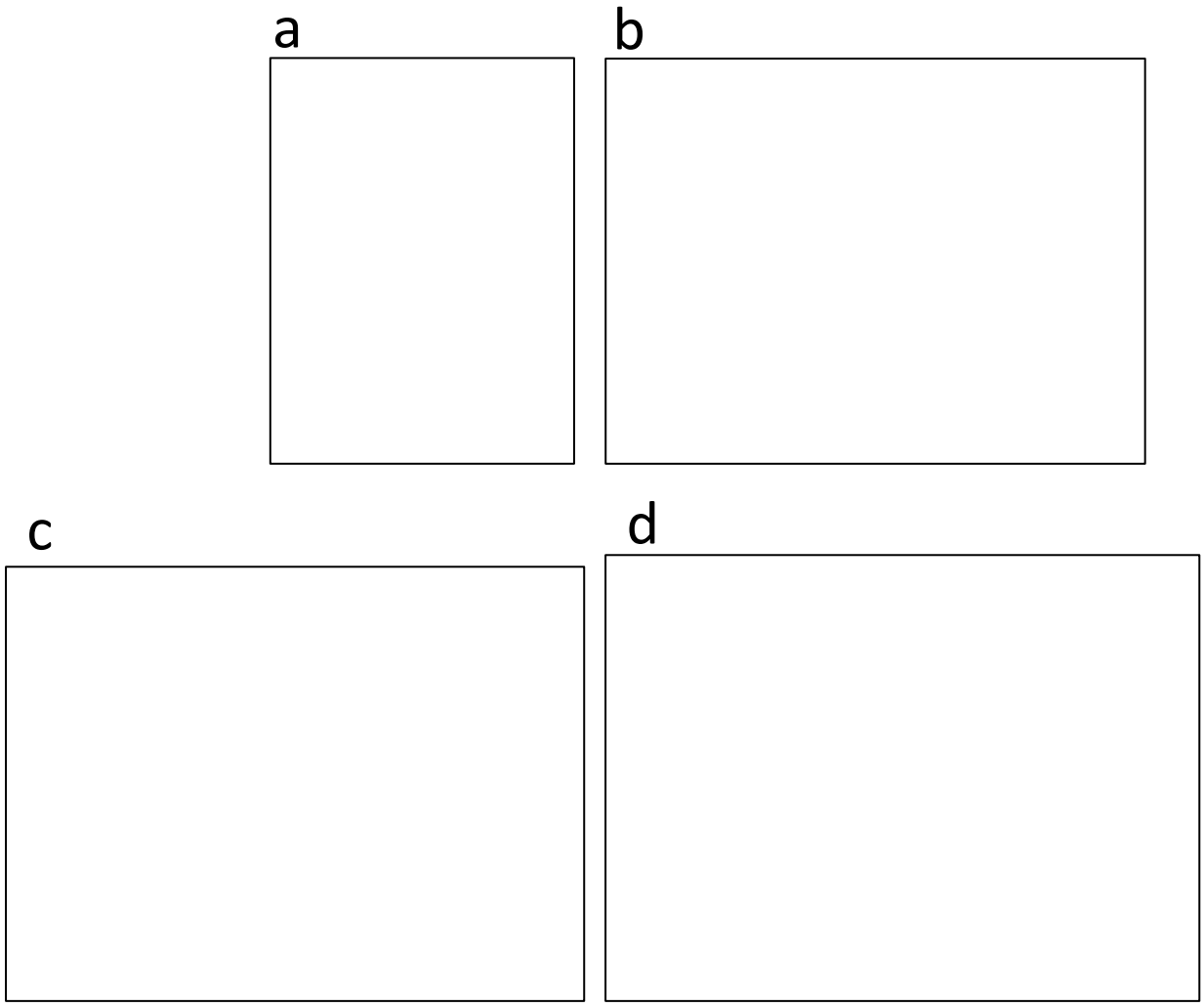

Figure 2. Human activity recorded during data collection: a) garbage, b) logging, c) fire, d) agriculture.