Losing ground but still doing well - *Tarsius dianae* in human-altered rainforests of Central Sulawesi, Indonesia

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1 Introduction

Sulawesi, one of the largest islands of the Malay Archipelago, provides living space for a unique fauna and flora. The island is characterized by vast numbers of endemic plant and animal species originating from the Australian as well as the Oriental region. The destruction and degradation of rain forest habitats pose serious threats to wildlife around the tropical world. On Sulawesi, recent population growth, resettlements, and social unrest have severely added to this problem, hence many of the island's endemic species face a highly unknown future.

Among the potentially endangered animals are the tarsiers (*Tarsius* spp.). These small nocturnal primates are not only unique in their phylogenetic origin and their appearance, the tarsiers' entanglement in Indonesia's myths, their distribution throughout Sulawesi, and their potential for eco-tourism make them – especially when considering the lack of big, charismatic animals on Sulawesi – potential flagship species for raising local awareness for nature.

Detailed field studies on its ecology and behaviour are needed to assess the conservation status of the genus *Tarsius* and to propose useful measures for securing its long-term survival.

Although the number of publications on tarsiers has grown immensely over the past decade (Crompton and Andau 1986, 1987; Dagosto and Gebo 1998; Fogden 1974; Gursky 1994, 1995, 1998a, b, 2000a, b, c; Leksono et al. 1997; MacKinnon and MacKinnon 1980; Merker and Mühlenberg 2000; Niemitz 1979, 1984a; Niemitz et al. 1991; Nietsch 1993, 1998, 1999; Nietsch and Kopp 1998; Nietsch and Niemitz 1992; Shekelle 1997; Tremble et al. 1993; Yustian et al. *in prep*), little emphasis has been given to conservation issues.

The focal species of this study is the Dian's tarsier *Tarsius dianae* Niemitz et al. Because it has just been described one decade ago (Niemitz et al. 1991), still little is known on the biology of this Central Sulawesi endemic. Tremble et al. (1993) were the first to investigate activity budgets, substrate use, and home range sizes. Merker and Mühlenberg (2000) compared population densities of *T. dianae* in habitats differently influenced by man and presented evidence that tarsiers are adaptable to specific kinds of human land-use, but do not tolerate others.

The study, parts of which are presented here, addresses parameters such as population densities, home range sizes, nightly path length, and group sizes of

T. dianae in habitats along a gradient of anthropogenic disturbance. Here, population densities will be focused on.

The research was designed to answer the following questions. To what extent do tarsiers tolerate human activities in the forest? If disturbed, what are their long-term reactions? Do they live "better" or "worse" in disturbed habitats than in pristine forest?

This study was conducted in the same area, partly on the same plots as done by Merker and Mühlenberg (2000). Hence, population densities of tarsiers on the same forest patches can be compared between 1998 and 2001, the years of data collection, and possible changes can be detected.

2 Materials and methods

2.1 Study objects

Tarsiers are small nocturnal primates inhabiting the islands of South-East Asia. Currently, six species are recognized, four of which live on Sulawesi and its adjacent islands (Groves 1998). With only 100-140g body weight and 12-13cm body length, tarsiers belong to the smallest primates on earth. Their scaly tail is about 25cm long, and – in the Sulawesi tarsiers – is characterized by a long tuft with long hair in the distal part of the tail. On Sulawesi, tarsiers exhibit a variety of colours of their usually thick fur, ranging from yellowish-brown to dark grey. Huge eyes, big ears, very long fingers and toes with enlarged terminal pads, and a strongly elongated tarsus are all prominent features of the genus *Tarsius*. They live in small family groups of up to 8 individuals (Gursky 1998a; MacKinnon and MacKinnon 1980). At dawn, when they retire to their common family sleeping sites, the adult and subadult Sulawesi tarsiers perform morning duets. These vocalizations are meant for territorrial advertising, the strengthening of social bonds, and mate attraction (MacKinnon and MacKinnon 1980; Niemitz 1984e, Nietsch 1999; Nietsch and Kopp 1998). The calls carry about 150m and are easily audible to the human ear. Tarsiers mark objects in their territory with urine or gland secretions (Niemitz 1984d). Fresh marking sites are easily recognizable by a very distinct smell. This is a simple way to check for the presence of these secretive nocturnal primates in a given area. Tarsiers exclusively feed on live animal prey (Niemitz 1984b, Nietsch 1993) with crickets, grasshoppers, moths, and other insects as their favourite captures.

Tarsius dianae which was described in 1991 by Niemitz et al. is the dominant species in Central Sulawesi (Nietsch and Kopp 1998). Until now, no sympatric tarsier taxa have been documented.

2.2 Study site and methodology

All data on *T. dianae* presented here were obtained in the vicinity of Kamarora, a ranger post at the north-eastern boundary of Lore Lindu National Park, Central Sulawesi, Indonesia (1°11'50" S, 120°08'15" E).

In 1998, four plots of natural forest with different forms of human land-use were investigated, in 2001, five patches of forest along a gradient of human disturbance were focused on. All plots were between 10 and 30ha in size.

To localize tarsier sleeping trees in a given area, we recorded all audible duet songs the animals performed every morning around dawn. By triangulating the positions of the call sources and multiple repetition of this procedure, tarsiers could be traced to their sleeping sites mostly comprised of strangler figs, dense shrubs, or bamboo stands. Mapping all sleeping sites in the investigated areas and measuring the distances between the groups resulted in relative population density estimates. To ensure comparability, the population densities given by Merker and Mühlenberg (2000) for 1998 were re-calculated using the same distance-to-density conversion scheme as in 2001.

Testing for statistically significant differences was done using the Wilcoxon signed-rank test and the Mann-Whitney U-test (Sokal and Rohlf 1995). For correlations, Pearson's r was computed (Lamprecht 1992). All tests are two-tailed.

In this study, we quantified anthropogenic disturbances using indicators suggested by Bynum (1999) for lowland forest of Lore Lindu National Park. In each habitat, we established 16 randomly distributed 10x10m plots and measured the number of artificial stumps, exotic plant species, rattan palms (*Calamus* spp.) less than 3m in length and rattans more than 3m in length. The rattans were later pooled for the calculation and the visual presentation (Fig. 1). Epiphytes less than 5m above the forest floor were counted as well as trees with a dbh of more than 50cm. The upper limit of the mossline was also measured or estimated. Integrating these parameters, a disturbance index D_i was developed:

$$D_i = 1/n \; \Sigma \; d_{ji} \tag{1}$$

D_i	=	disturbance index for habitat i
n	=	number of recorded disturbance parameters
j	=	disturbance parameter (1 ... n), e.g. stumps
d_{ji}	=	relative disturbance index for parameter j in habitat i, e.g. 0.2
v_{ji}	=	value for parameter j in habitat i, e.g. 6 stumps or 6 big trees
$v_{j \, max}$	=	maximum value for parameter j over all habitats, e.g. 12 stumps
$v_{j \, min}$	=	minimum value for parameter j over all habitats, e.g. 3 big trees

For parameters where the maximum value means maximum disturbance (e.g. stumps), d_{ji} is

$$d_{ji} = v_{ji} / v_{j \, max} \tag{2}$$

If $v_{j\,min} = v_{j\,max} = 0$, then $d_{ji} \overset{def}{=} 0$ $\hspace{6cm}$ (3)

For parameters where the minimum value means maximum disturbance (e.g. big trees), d_{ji} is

$d_{ji} = v_{j\,min} / v_{ji}$ $\hspace{3cm}$ (if $v_{j\,min} > 0$) $\hspace{3cm}$ (4)

$d_{ji} = (v_{j\,max} - v_{ji}) / v_{j\,max}$ $\hspace{2cm}$ (if $v_{j\,min} = 0$) $\hspace{3cm}$ (5)

If $v_{j\,min} = v_{j\,max} = 0$, then $d_{ji} \overset{def}{=} 1$ $\hspace{6cm}$ (6)

The disturbance index D_i – in the form described above – is suitable to compare the relative degrees of disturbance of plots *within* a study. If it is to be used for a comparison *between* studies, all parameter values for all studies have to be known, for the disturbance indices D_i cannot be obtained independently and then compared. For that, $v_{j\,min}$ and $v_{j\,max}$ constitute the absolute minimum and maximum values for all studies.

3 Results

3.1 Disturbance index D_i for five habitats in 2001

In 2001, instead of describing a land-use form as in 1998, a disturbance index D_i was developed reflecting the degree of human intervention. Five habitats were characterized this way (Fig. 1 and Fig. 2). These areas were chosen along a gradient of disturbance estimated by the observers, with primary forest and heavily disturbed habitat at the extremes. The quantitative analysis using D_i shows a slightly different picture. Here, Habitat 3 (H3) is relatively more disturbed than Habitat 4 (H4), although by looking at it, one would have rated H4 to be affected more severely. This is mostly due to a high number of exotic plants, namely coffee and cocoa, in H3, which is an area with many small forest gardens.

Depletion in rattan palms is also more pronounced in H3. The number of big trees and the number of artificial (branch and tree) stumps resulting from logging or trail-cutting follow a gradient steadily decreasing from H1 to H5, hence the relative disturbance indices d_{ji} for these parameters increase. Fig. 2 depicts the disturbance index D_i for each of the five areas in question. Although, due to the calculation method and also due to some old stumps found in this habitat, the primary forest plot has an $D_1 > 0$, this area is refered to as "undisturbed". Disturbance is most severe in Habitat 5. For all measured parameters j, the relative disturbance indices $d_{j5} = 1$, i.e. anthropogenic influences are at their maximum compared to the other four habitats. This results in $D_5 = 1$.
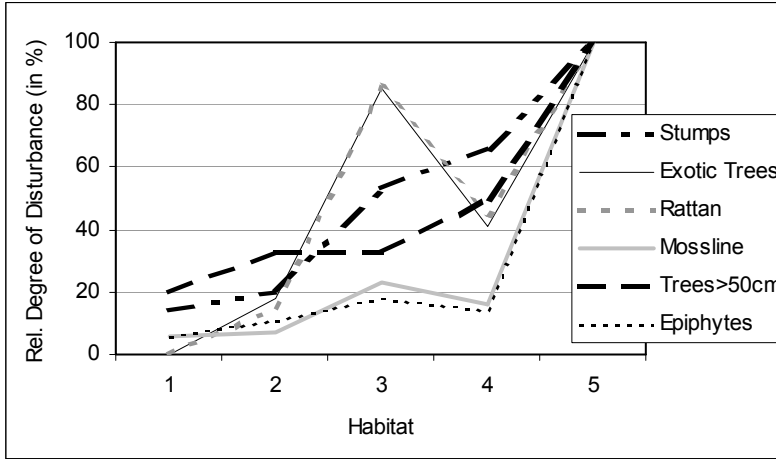
Fig. 1. Relative degree of disturbance in five different forest habitats of Lore Lindu National Park, Sulawesi. Separately for each disturbance parameter, the value in relation to the maximum value found among all habitats is shown (= d_{ji}*100%).
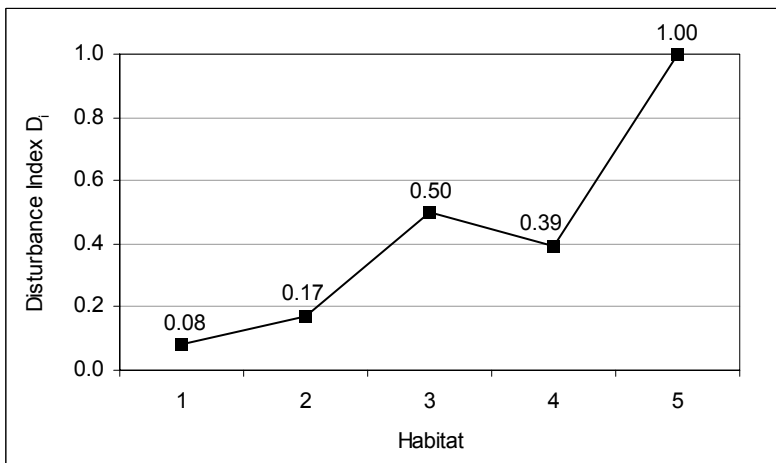

Fig. 2. Disturbance index D_i for each of five different forest habitats of Lore Lindu National Park, Sulawesi. The index has been calculated from the number of stumps, exotic trees, rattan palms, epiphytes, big trees, and the height of the mossline. $D_i = 0$ stands for pristine conditions, $D_i = 1$ means maximum disturbance compared to the other study habitats.

3.2 Population densities along a gradient of human disturbance

Looking at tarsier population densities along this gradient of disturbance, a clear trend is visible (Fig. 3). While in undisturbed forest, a density of 5.7 groups/10 ha could be found, there are significantly fewer tarsier groups in all investigated areas that are affected by human land-use (**U-test). There are no significant differences between tarsier population densities in the areas with slight or medium disturbance. On the plantations outside of the natural forest, only 1.4 groups/10ha were found. Here, the density is significantly smaller than in primary forest**, in secondary forest*, and in the area with interspersed forest gardens* (U-test). On plantations, tarsiers sleep in dense shrubs, bamboo stands, and remnant strangler figs. They prefer dense undergrowth for hunting, but also use coffee and cocoa plants as locomotor supports. There is a significant negative correlation between tarsier population density and the intensity of anthropogenic disturbance (Pearson, r= -0.89*).

We could not find tarsiers in paddy fields or in tea, clove, corn and coconut monocultures. Nevertheless, some groups manage to stay very close to human settlements or at roadside shrubs and bamboos.

3.3 Population densities in 1998 and in 2001

Population densities of *T. dianae*, obtained in 2001 using the same methodology as in 1998 are generally lower than three years before (Table 1). In 1998, 10.5 tarsier groups/10ha were found in primary forest, in this study, only 5.7 groups/10 ha could be recorded. However, due to the conversion of the primary forest plot of 1998 into plantations, another pristine forest was chosen for the study in 2001, hence the data are not directly comparable. While in 1998, the primary forest as well as the other three habitats were located at an elevation of 700-750m asl, in 2001, no pristine or virtually undisturbed forest patch of at least 10ha in size could be found below the elevation of 950m asl. The chosen primary forest study plot of 2001 is situated at an elevation of 950-1,020m asl. While secondary forest and plantations outside of the natural forest were only investigated in 2001, small-scale logging and small (<0.5ha) forest gardens played a major role in both studies. Population densities in two parts of the forest that were already screened in 1998 were also measured in 2001, hence direct evidence for habitat change can be drawn from the comparison of these data. In 1998, a forest patch characterized by small-scale logging contained on average 4.3 tarsier groups per 10ha. In 2001, the logging had almost ceased, and a number of interspersed forest gardens (coffee and cocoa) could be found. With 3.8 family groups per 10ha, the population density was not significantly different (Wilcoxon) from three years before. However, if this kind of habitat, namely forest with small plantations, is compared with the same habitat type studied in 1998, a dramatic decrease in tarsier population density is apparent (Table 1 and Fig. 4).

Table 1. Relative population densities of *T.dianae* in several habitats of Lore Lindu NP in the years 1998[1] and 2001.[2]

Habitat type	Population density			
	1998		2001	
Primary forest	10.5 gr./10ha	(n=7)	5.7 gr./10ha	(n=6)
Secondary forest			3.6 gr./10ha	(n=6)
Forest with small planta-tions	12.0 gr./10ha	(n=7)	3.8 gr./10ha	(n=6)
Forest with small-scale logging	4.3 gr./10ha	(n=8)		
Forest with logging and plantations	6.6 gr./10ha	(n=8)	3.3 gr./10ha	(n=5)
Plantations outside of the natural forest			1.4 gr./10ha	(n=5)

[1] Density data re-calculated from Merker and Mühlenberg (2000) using the same distance-to-density conversion scheme as in 2001 (this study).
[2] Arrows indicate specific study patches investigated in both years. In one case, the type of land-use changed between 1998 and 2001.

One more specific forest patch – "forest with logging and plantations" – was looked at in both data collection periods. Ongoing logging and conversion of the forest into plantations resulted in a significant decrease of the tarsier population density in this area (*Wilcoxon). While in 1998, on average 6.6 groups could be found per 10ha plot, in 2001 the density had decreased to 3.3 groups/10ha. This change went along with visible degradation of the forest. Fig. 5 shows a map of this area.
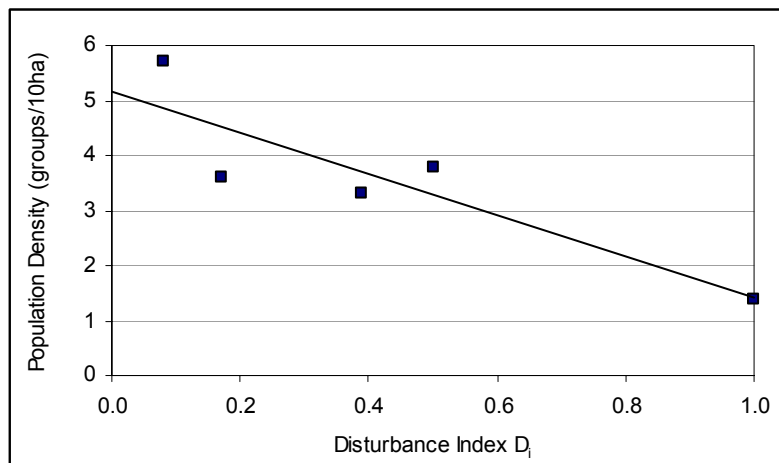

Fig. 3. Relative population densities of *T. dianae* in five different forest habitats of Lore Lindu National Park, Sulawesi. The disturbance index for each area has been calculated from the number of stumps, exotic trees, rattan palms, epiphytes, big trees, and the height of the mossline. $D_i = 1.0$ means maximum disturbance.
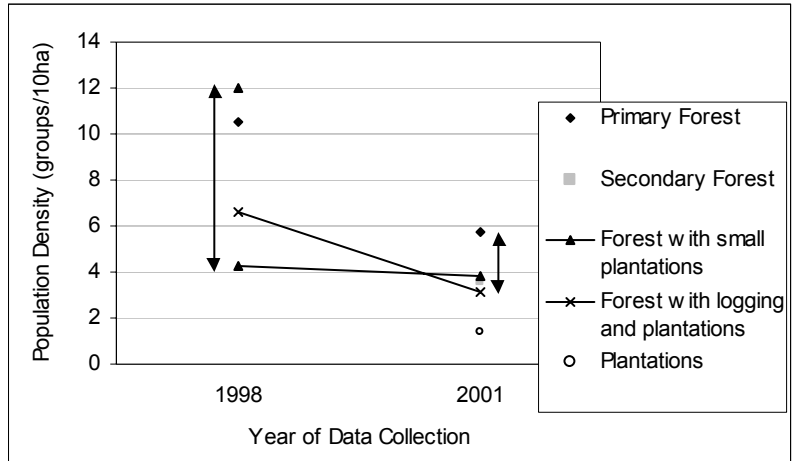
Fig. 4. Comparison of relative population densities of *T. dianae* in several habitats of Lore Lindu NP between the years 1998 and 2001. Connected data points reflect specific plots investigated in both periods. Arrows indicate the range of tarsier densities in habitat types focused on in both studies. Habitat descriptions given were valid in 2001 and are not entirely consistent with 1998 (see table 1).
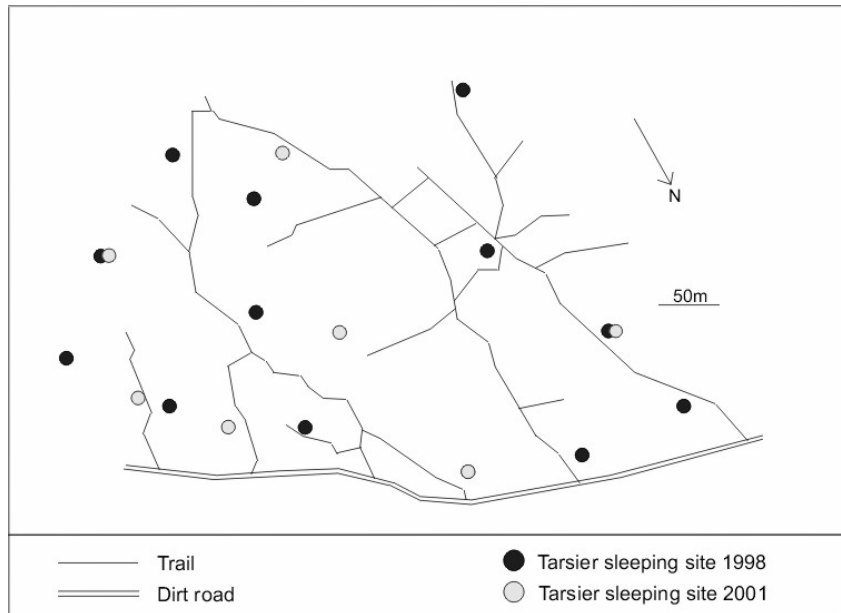

Fig. 5. Map of Habitat 4, forest with logging *and* plantations. Dark circles represent tarsier sleeping sites in 1998, light grey circles depict sleeping sites in 2001. The trail system is shown as existent in 1998. The dirt road runs along the north-eastern border of Lore Lindu NP.

4 Discussion

4.1 Usefulness of the disturbance index D_i

The disturbance index D_i provides a possibility to quantify anthropogenic influences and to compare these between habitats. This way, interval/measurement data instead of nominal or ranked variables can be produced, and these can be correlated with the variates in question. This would also be possible by using just one parameter, e.g. the number of stumps. However, calculating D_i gives a more comprehensive notion of anthropogenic effects to the forest.

The index D_i as presented here has been designed to compare relative disturbances of plots of one study (data collection in 2001). Because of different minimum and maximum parameter values for different studies, it is not possible to calculate D_i and then directly compare it with the disturbance indices of a different data set. Instead, data of the different studies have to be pooled producing new extreme values, and D_i have to be calculated anew. As obtaining the complete data sets of other researchers is – in most cases – very difficult, this limits the use of D_i in comparing *between* studies. Additionally, different forest types are characterized by different natural conditions dependent of climate, elevation, topography, geology etc. Indirect indicators for disturbance, e.g. the number of big trees, rattans, and epiphytes, or the upper limit of the mossline are no useful variables to compare montane with lowland forests, or lowland rainforest with mangrove forest. Only direct disturbance indicators such as the number of stumps or exotic trees should be used when comparing different types of forest.

This study uses the "forest integrity indicators" suggested by Bynum (1999). Using statistical analyses, he identified the seven variables mentioned above to detect anthropogenic disturbance. To facilitate comparison, the same variables should be employed in future studies.

4.2 Population densities along a gradient of human disturbance

There is a strong negative correlation between population densities of *T. dianae* and the intensity of human disturbance of the forest. Highest densities occur in undisturbed primary forest, the lowest number of tarsier groups per area we found in plantations, i.e. heavily disturbed habitat. This finding does not fully confirm the results of Merker and Mühlenberg (2000) who detected the highest population density of *T. dianae* in a slightly disturbed area, i.e. in forest with interspersed plantations (see also 4.3). However, they also state that primary forest harbours almost as many groups of tarsiers as the habitat mentioned above. The density estimates agree with the numbers given by Gursky (1998a) for *T. spectrum* in Tangkoko Nature Reserve in North Sulawesi. She found 5.6 groups/10ha of mixed forest but did not differentiate between habitat types. MacKinnon and MacKinnon (1980) estimated densities of *T. spectrum* in several localities and for a variety of habitats. Listening to the duet songs the tarsiers performed every morning, they

found between 3 and 10 individuals per ha. With an average of about 3 members per family group (Gursky 1998a, unpublished data), these numbers correspond to between 10 and 30 groups per 10ha of forest. The latter number is exceptionally high and has been given for thorn scrub at sea level. Whether this habitat type is as "good" as it seems or whether the differences in population densities given by Gursky and by MacKinnon and MacKinnon are due to different methodology remains unclear.

Niemitz (1979) gives a density of 80 individuals per km^2 for *T. bancanus* in Borneo. Assuming a group size of 3, this would mean an average of 2.7 groups/10ha. Considering the different sociality of this tarsier species, comparisons with the Sulawesi tarsiers are difficult, though this number is well within the range of the densities given for *T. dianae* in this study.

Looking at the parameter of population density, we would rate primary forest to provide the best living conditions for tarsiers in Lore Lindu National Park. However, home ranges of female *T. dianae* in Kamarora are smallest in slightly disturbed forest indicating optimum conditions in this habitat (Merker and Mühlenberg 2002, unpublished data). Whether a patch of forest is "better" or "worse" for tarsiers than others cannot be drawn from one single parameter alone. Instead, a set of variables would be needed to estimate habitat quality more reliably. Nevertheless, the significant negative correlation between tarsier density and human disturbance is unmistakable and constitutes a strong reason for conserving what's left of undisturbed forest.

Coffee and cocoa plantations outside of the forest only provide poor living conditions but might serve as stepping stones for the colonization of other forest patches or for the recolonization of a logged and re-grown area. It is crucial for the survival of tarsiers on plantations that there are potential sleeping sites which give shelter from view, predators, and weather, that there is a high abundance of prey items, i.e. large insects, and that the locomotor supports are not spaced too far apart (>2m). In a "clean" plantation without uncultivated patches and with intensive use of pesticides, no tarsiers can survive.

For the reasons named above, paddy fields, corn, clove, tea and coconut monocultures do not permanently harbour tarsiers.

4.3 Population densities in 1998 and in 2001

While in 1998, the population density in primary forest was an estimated 10.5 groups/10ha, in 2001, only 5.7 groups/10ha were found in pristine habitat. This is probably due to several factors: 1. There is variability between different plots even of the same habitat type. Demographic factors causing fluctuations in sleeping tree distances might play a major role. 2. The primary forest plot of 1998 is situated at 700m asl, the plot of 2001 at 950m asl. According to Whitmore (1984, 1990), one patch falls into the zone of lowland rainforest, the other one belongs to lower montane forest. Availability of prey or locomotor supports might influence the density of tarsiers. However, considering the appearance of both plots, and taking into account that insect abundance estimates in 1998 and 2001 revealed no

significant differences (unpublished data), we do not believe the slight contrast in elevation to be of great importance to tarsiers. 3. One more cause for variety might arise from the distinction which forest has been disturbed and which has not been affected by human activities. For instance, the undisturbed study plot of 1998 was characterized by a high number of bamboo stands, none of which could be found on the patch of 2001. Bamboos are favoured by fire and other disturbances (Whitmore 1984). Hence, although there has not been any detectable current or recent disturbance in 1998, and bamboos are not a direct indicator of disturbance, the designation as pristine forest might have been imprecise.

While on one plot investigated in both studies, the population density of *T. dianae* did not change significantly over the course of three years, another one was characterized by a dramatic decrease in tarsier numbers. Although logging and agroforestry occured in both data collection periods, the intensity of human land-use was much higher in 2001, and a high proportion of the forest had already been converted into small cash-crop plantations. Ongoing logging was also severe. After the data acquisition in early 2001 had been completed, this patch was almost clear-cut, and virtually no tarsiers remained in the area. Here, the threshold of severe effects of human disturbance had been crossed, while in other areas, tarsiers were able to cope with a variety of human activities in the forest.

Generally, population densities decline in the study area. Possibly, the year 1998 was characterized by exeptionally good conditions for tarsiers, because so many groups could settle in a small area. On the other hand, these animals are very territorial, long-lived, and raise at maximum one offspring per adult female per year, so major fluctuations between one year and another cannot be expected. Considering the unaltered number of members per family group (unpublished data), no fission or fusion processes were apparent. A high mortality or pronounced emigration seem to have caused the drastic decline in tarsier densities over the last few years. This goes along with recent degradation of the forest and a huge increase in human population density along the margin of Lore Lindu National Park. In particular, a new concrete road leading from Tongoa to Kamarora Field Station attracted many new human settlers to that area. The negative impact of this infrastructural improvement on the park's biodiversity is unmistakeable.

5 Conclusion

Although population sizes decline, future prospects are not too gloomy for *T. dianae* because this species is adaptable to widespread human uses of the forest. Moreover, under certain conditions, cash crop plantations can play a vital role for these small primates, giving additional hope that they may be saved from extinction. However, the area has to be forested to some extent. Tarsiers need sleeping sites, dense undergrowth as locomotor supports, and a high abundance of insects as food source. Controlling the illegal logging in the study area is the single most important action to be taken in order to greatly enhance the chance of survival of

this fascinating species. The results of these studies are being included in management plans of several Indonesian authorities.

6 Acknowledgements

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