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Modelling the habitat use and distribution of the threatened Javan slow loris *Nycticebus javanicus*

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ABSTRACT: The Javan slow loris *Nycticebus javanicus* is threatened by habitat decline and is classified as Critically Endangered on the IUCN Red List. Information on its distribution and habitat preferences is still lacking, and so far the distribution of the Javan slow loris has only been quantified via ecological niche modelling based on museum specimens and remotely derived environmental layers. We aimed to refine the modelled predictions and to verify the distribution of the Javan slow loris by collecting up-to-date occurrence data, which are fundamental for conservation and management of the species. Furthermore, we identify variables that predict its presence and give recommendations for future survey sites and conservation actions. From April to June 2012 we collected data on species presence, habitat preferences and levels of disturbance at priority sites throughout Java. We present a map of the predicted distribution of *N. javanicus* based on a maximum entropy model. We investigated habitat preferences using R (v. 2.14.1). During the study we sighted 52 lorises in 9 out of 14 investigated areas. The amount of bamboo in a forest had a positive effect on the encounter rates. Furthermore, we made 86% of sightings in forest plantations and agricultural areas located outside protected areas, with the majority located in areas with measured high levels of disturbance. We suggest that further ecological studies are needed to understand if and why densities may be higher in anthropogenically disturbed areas.

KEY WORDS: Lorisidae · Maximum entropy · Nocturnal primate · Java · Species conservation

INTRODUCTION

Biodiversity hotspots cover only 2.3% of the Earth's land surface, but host 42% of the world's vertebrates (Jha & Bawa 2006). None of these hotspots has more than one-third of its pristine habitat left, and all of them face deforestation caused by population growth and development; this pressure is especially high in the tropics (Brooks et al. 2002, Jha & Bawa 2006). The tropical rain forests of Sundaland, being part of a biodiversity hotspot, faced the highest deforestation rate in all of East Asia from 2000 to 2010 and are greatly

in need of conservation actions (Giam et al. 2011). Indonesia, part of the Sundaland hotspot and arguably home to one of the world's highest diversity of primates (Nekaris et al. 2008a), is subject to a yearly deforestation rate of 21 000 km² (Santilli et al. 2005). This is especially true of Java, one of the most populated islands in the world (Smiet 1999), where biodiversity is being severely affected by extreme population growth and deforestation (Miettinen et al. 2011).

It is important to know how species in areas threatened by deforestation will respond to the modification of their habitat (Johns & Skorupa 1987). Whilst some

species may adapt positively to living in human-modified areas (Sodhi et al. 2010), for most, increasing anthropogenic changes in the landscape lead to decreased habitat quality (Fahrig 2007). Subsequent population fluctuations can be due to loss of food sources, contraction of home ranges and easier accessibility for poachers (Johns & Skorupa 1987, Cuaron 2000, Sodhi et al. 2010). Habitat fragmentation and increased isolation of forest patches are likely to adversely affect species, particularly those with low mobility and dispersal abilities (Fahrig 2007, Ferraz et al. 2007). In order to develop conservation plans for species in regions threatened by deforestation and habitat change, collection of data on their habitat preferences, as well as the availability of suitable habitats in an area, is vital (Johns & Skorupa 1987). Recent conservation tools for assessing the habitat requirements of species include models which relate species distributions to environmental characteristics (Guisan et al. 2006). Such models provide a valuable tool to support the selection of protected areas (PAs) which maximise the conservation of biodiversity (Rodriguez et al. 2007).

The Javan slow loris *Nycticebus javanicus*, endemic to Java, is severely threatened by both habitat loss and the wildlife trade (Nekaris et al. 2008b). The species is considered one of the 25 most endangered primates in the world (Mittermeier et al. 2009). Consequently, Javan slow lorises are listed in Appendix I of CITES and are classified as Critically Endangered on the IUCN Red List (Nekaris et al. 2008b, Nekaris et al. 2013). Recent line-transect surveys have recorded extremely low encounter rates in this species, as low as 0 to 0.11 animals km^{-1} (Nekaris et al. 2008a). Despite the high levels of threat faced by Javan slow lorises, our knowledge of their habitat preferences is limited. Nocturnal and cryptic in appearance and behaviour, the Javan slow loris specialises in non-saltatory arboreal climbing (Runestad 1997, Pliosungnoen et al. 2010). As a result, lorises have a limited ability to move over gaps and prefer habitat where maintaining contact with the substrate at all times is facilitated (Runestad 1997), making them especially vulnerable to habitat fragmentation.

Recently, the potential distribution of *Nycticebus* species in Indonesia was modelled using MaxEnt (Phillips et al. 2004, 2006), a machine learning tool based on an algorithm of the maximum

entropy principle (i.e. closest to uniform) (Thorn et al. 2009). The authors provided a preliminary indication of potential habitat for Javan slow loris conservation, revealing that a large proportion of Javan slow loris′ habitat was predicted in areas with high anthropogenic risk (Thorn et al. 2009). The data used in this study were largely limited to those collected from museum specimens and literature reviews, and included minimal ground-truthing. The authors recommended potential survey sites where the species had not been previously recorded and suggested that new records of species locations would influence the shape of their modelled potential distribution.

Here, using up-to-date occurrence data collected from forest surveys, we have remodelled the ecological niche and refined the existing predictions of the potential distribution of *N. javanicus*. Furthermore, we investigated the habitat preferences of this species and identified environmental variables that predict its presence. The outcomes of this study will inform the conservation of this threatened species and will be used to provide recommendations for future survey sites.

MATERIALS AND METHODS

Study sites

We conducted forest surveys from April until June 2012 on Java, Indonesia (Fig. 1). The average precipitation on Java is 1650 mm, and the annual average temperature varies between 26 and 29°C at sea level,
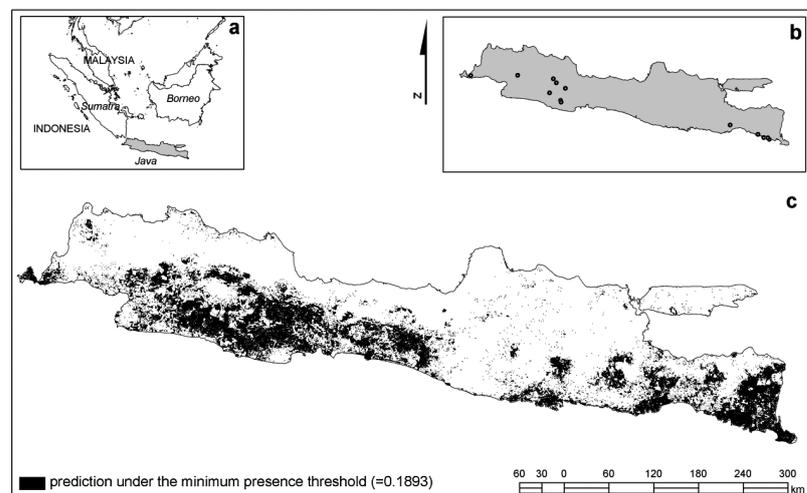

Fig. 1. (a) Location of Java in Indonesia, (b) the 13 localities of *Nycticebus javanicus* used in the MaxEnt model, and (c) the resulting predicted habitat suitability (constrained to the 24 variables used) from the MaxEnt model for *N. javanicus* under the minimum presence training threshold (= 0.1893) (area in black)

Table 1. Forest categories used during the surveys. The forest types were acquired based on observations at each site

Forest type	Description
Late-stage secondary forest	Relatively pristine old-growth forests that experienced minimal disturbance but where effects are no longer evident
Secondary forest	Forests that have experienced major disturbance (in most cases severe logging) but have re-grown
Forest plantations	Areas used for timber production or the plantation of gum trees or fruiting trees interspersed with some remaining forest patches
Agricultural areas	Areas used for agriculture interspersed with remaining forest patches and some old trees

Table 2. Methods used for habitat measurements. DBH: tree diameter at breast height

Habitat measurement	Method
Tree density	t-square method (Hill et al. 2007)
DBH	Of first and second trees used for t-square (Hill et al. 2007)
Tree height	Of first tree used for t-square, using range finder
Connectivity	Of first tree with surrounding trees (direct contact or distance <1 body length of a loris)
Visibility	Measured from the spot where the observer stopped, at a right angle to the transect. The furthest visible point was taken, and distances were measured using a range finder.
Anthropogenic disturbance	Litter: amount of litter in a 2.5 m radius around the observer. Each individual piece of litter was counted. Anthropogenic noise: presence/absence of anthropogenic noise (e.g. dog barking, traffic, voices) whilst at the measurement point. Logging: number of logged trees visible in the area around the measurement point.

Data collection

We walked 1 to 3 line transects (Sutherland 2006) in separate areas of forest and on separate nights at each of the study sites. We walked each transect at an average speed of approximately 400 m h^{-1} (Nekaris et al. 2008a). During transects we scanned all levels of vegetation using headlamps with a combination of red (Nekaris et al. 2008a) and white filters. For each sighting of a Javan slow loris, we determined the perpendicular distance of the animal from the transect, the number of individuals, the height of the animal in the tree and the tree species (Nekaris et al. 2008a). We started all surveys between 18.00 and 19.00 h and ended them between 23.00 and 02.00 h. For each transect, we recorded the exact GPS location, date, time and weather conditions (Sutherland 2006).

Environmental variables

On transects, we collected data on different environmental variables with relevance to the habitat and protection requirements of slow lorises (Kumara et al. 2006, Thorn et al. 2009, Pliosungnoen et al. 2010). We conducted transects in forested areas, categorised as late-stage secondary forest, secondary forest, forest plantations, or agricultural areas (Table 1).

We recorded occurrence of the species inside and outside of PAs. To account for the habitat preferences of *N. javanicus*, we took habitat measurements every 50 m (Table 2) of the densities, height and diameter at breast height (DBH) of trees, the connectivity of trees, forest type, the main tree species and the occurrence of bamboo (Poaceae) and fairy duster *Calliandra calothyrsus* Meisn. (cf. Dykyj 1980, Runestad 1997, Singh et al. 1999, Nekaris et al. 2005) on each transect. Bamboo and fairy duster have previously been identified as possibly having an impact on the presence of Javan slow lorises (Starr et al. 2011, Moore 2012). The relative abundance of bamboo was considered the percentage of bamboo among all trees recorded on a transect during the 50 m measurements.

with temperatures dropping considerably with increasing altitude (Dunn et al. 2011). Java is nearly entirely of volcanic origin, and altitudes vary between 0 and 3676 m (Siswowidjoyo et al. 1997). We chose the study sites according to those identified by Thorn et al. (2009) to be favourable for the Javan slow loris *Nycticebus javanicus* and according to studies on Javan slow loris distribution conducted by Winarti (2003, 2011) and Wirdateti (2012), as well as previous experience of one of the authors (K.A.I. Nekaris). We surveyed 8 sites within PAs and 6 sites outside of PAs (Table S1 in the Supplement at www.int-res.com/articles/suppl/n023p277_supp.pdf).

To account for anthropogenic disturbance we collected information on the amount of human litter, anthropogenic noise and evidence of logging (Rode et al. 2013). We also recorded visibility, the time of day and the group size of observers (Lardner & Savidge 2007, Pliosungnoen et al. 2010).

Habitat suitability modelling

We used the maximum entropy general purpose machine learning method, which has been adapted and specifically developed as a software (MAXENT v. 3.3.3k) for species-distribution modelling (Phillips et al. 2004, 2006). The method has been proven to out-compete other modelling approaches in studies with very low sample sizes (Hernandez et al. 2006, Wisz et al. 2008). It combines biological data of species occurrence with environmental characteristics to estimate the probability distribution of maximum entropy over the study area, subject to the set of constraints provided (i.e. environmental characteristics where the species occurs). From among all distributions satisfying these constraints, the one of maximum entropy, i.e. the one that is closest to uniform or the most spread out is chosen to obtain the predicted distribution (Phillips et al. 2004, 2006). We used a 10-fold cross-validation replication run type with the program's default parameters (Phillips & Dudik 2008). We included 24 variables in the model: 19 bioclimatic layers (Hijmans et al. 2005, www. worldclim.org/current), elevation (http://srtm.csi. cgiar.org/), land cover in 2009 (with 12 categories within Java, http://due.esrin.esa.int/globcover/), percentage of forest cover in 2010 (http://glcf.umd.edu/ data/vcf/), distance to roads and distance to cities. For all variables, the same geographic extent (Java), cell size (0.008333 decimal degrees) and geographic coordinate system (GCS World Geodetic System [WGS] 1984, http://web.archive.org/web/201204021 43802/https://www1.nga.mil/ProductsServices/Geo desyandGeophysics/WorldGeodeticSystem/Pages/ default.aspx) were selected. To avoid model overfitting (Dormann et al. 2007, Merckx et al. 2011), we corrected occurrence data for spatial autocorrelation by selecting 1 random locality in a 5 km radius, resulting in n = 13 occurrence points (n = 56, i.e. 52 sightings from the present study and 4 additional localities from independent surveys). Outputs were processed and analysed in ArcGIS 9.3. As a model power assessment, we report the model's area under curve (AUC) of the receiver-operating characteristic (ROC) of test locations randomly set aside

during the 10 replication runs. We created a binary map (i.e. suitable vs. unsuitable) using the 'minimum training presence threshold', which has been commonly used when occurrence data are highly reliable, such as here, given the confirmed species identifications and records in their primary habitat. We ran a threshold-dependent validation test, the jackknife validation method for samples n < 25 described by Pearson et al. (2007), which assesses whether the model successfully predicts the 13 omitted localities (1 locality is randomly set aside at each of the 13 replications) within the area of suitability (chosen under the minimum training presence threshold). This is assessed with a p-value based on the test statistic D; $D = \Sigma X_i (1 - P_i)$, where X_i is the success–failure variable indicating whether the ith omitted locality is included or not in the predicted area and P_i is the probability of success (Pearson et al. 2007). The p-value is computed with the pValue compute program (Pearson et al. 2007). We present variable environmental characteristics within the resulting predicted potential distribution.

We compared the area of predicted potential distribution from our model to the predicted potential distribution by Thorn et al. (2009) and assessed the proportion of potential habitat located within PAs.

Statistical analysis of habitat preferences

We performed the statistical analysis of habitat preferences in R (v. 2.14.1). We used general linear mixed models (GLMM) to provide a first indication of the value of current PAs for the conservation of *N. javanicus.* Furthermore, we also used a variety of GLMMs (Table S2 in the Supplement at www.int-res. com/articles/suppl/n023p277_supp.pdf; for variables and random effects) to investigate the importance of the habitat variables bamboo, forest type, altitude and tree height, and tested the visibility and time of day in a variety of models to determine whether they accounted for variations in the encounter rates of *N. javanicus* at different sites.

We used general linear models (GLM) to check visibility for its consistency throughout the habitat variables bamboo and forest type, as it has an effect on the encounter rate (Lardner & Savidge 2007). Moreover, we used GLMs to test the impact of the time of day on encounter probabilities, to ensure that the results were not biased due to certain activity patterns of *N. javanicus* and to test the impact of human litter, anthropogenic noise and logging on encounter probabilities (Table S2 in the Supplement). For all

statistical tests we identified minimal adequate models using model simplification tests with maximum likelihood (REML) to account for the effect of individual explanatory variables (Crawley 2007).

RESULTS

During the 3 mo study period we sighted 52 Javan slow lorises *Nycticebus javanicus* in 9 of the 14 study areas.

Habitat suitability model

Our predictive model generated an average test AUC of 0.899 (0.713 to 0.998). The jackknife validation method showed significant successful prediction of the test localities under the minimum training presence threshold, with a success rate of 0.85 (p < 0.01) (Table S3 in the Supplement at www.int-res.com/articles/suppl/n023p277_supp.pdf; for means and standard deviation [SD] of general environmental characteristics). The habitat suitability model showed that only one-fifth of the predicted suitable habitat for *N. javanicus* is located within PAs (Table 3).

Habitat preferences

The average probability of encountering *N. javanicus* varied greatly among the different sites (Table 4). Results varied from 0 to 1.79 sightings km^{-1}.

The encounter rate for *N. javanicus* was significantly higher in forested patches outside of PAs (lmer, $x^2_{1,3}$ = 6.8198, p < 0.01). We observed 31.45 km of

transects (15 surveys) within PAs, resulting in 7 sightings, and 34.86 km of transects (12 surveys) outside PAs, resulting in 45 sightings; although 16 of the sightings made outside PAs were in close proximity to a PA (Fig. 2). The majority of sightings occurred in West Java, but 1 sighting was made in East Java, in Meru Betiri National Park. During the study considerably more survey effort was invested in West Java.

Analysing the habitat features, we found significant effects of the presence of bamboo and forest type on presence of *N. javanicus* (forest type [lmer, $x^2_{3,6}$ = 10.135, p < 0.01], bamboo [lmer, $x^2_{3,4}$ = 10.813, p < 0.010]). The higher the amount of bamboo on a transect, the higher the encounter rates with Javan slow lorises per kilometer (GLM, $x^2_{22,23}$ = 40.356, n = 24, p = 0.03; Table S4 in the Supplement at www.int-res.com/articles/suppl/n023p277_supp.pdf) (Fig. 3). The encounter rate with *N. javanicus* varied significantly between the 4 forest types (lmer, p < 0.05; Table S4). We made the most sightings per km in agricultural areas (kebun) and forest plantations (Fig. 3); this was possibly influenced by higher visibility in agricultural areas, although no significant difference in visibility between the different forest types could be proven.

Visibility on transects had a significant influence on the number of *N. javanicus* sighted (GLM, $x^2_{4,9}$ = 27.604, p < 0.01). An effect of forest type on visibility was not detected, but there was a trend towards higher visibility in the agricultural areas than in other areas (GLM, p = 0.057; Table S4, Fig. 4). The reason this trend is not significant is likely due to the high variance in this category.

We found significantly higher numbers of *N. javanicus* in areas with greater levels of logging or anthropogenic noise (logging [GLM, p < 0.01], noise [GLM, p < 0.01]; Table S4).

DISCUSSION

Habitat suitability model

When MaxEnt has been used for primates, including brown-backed bearded sakis and black uakaris in the northwestern Amazon (Boubli & Lima 2009), brown-headed spider monkeys in Ecuador and southern Colombia (Peck et al. 2011), mantled howler monkeys, black howler monkeys and spider monkeys in southern Mexico (Vidal García & Serio Silva 2011), or

Table 3. Size of the predicted distribution on Java (in km^2) calculated using the minimum presence training threshold, and proportion (km^2 and %) of this area found within protected areas (PAs), including National Parks, Natural Reserves, and other designated area categories (data from protectedplanet.com). For comparison, the predicted distribution and the amount of calculated low risk habitat determined by Thorn et al. (2009) are given where available

	Present study	Thorn et al. (2009)
Predicted distribution on Java	29323 km^2	12523 km^2
Predicted distribution within PAs	5829 km^2 (20%)	–
Suitable habitat classified as low risk areas[a]	–	5%

[a]Proximity to protected area <20 km, size of forest patch >40 km^2, proximity to populated areas >10 km, proximity to roads >10 km, proximity to agriculture >5 km)

Table 4. The amount of bamboo and the probability of encountering *Nycticebus javanicus* according to study site and the main tree species found at each study site. **Bold** type indicates sites located within protected areas. As encounter rates do not account for detectability, we also defined classes as follows — low: 0 to 0.75 encounters km^{-1} transect; medium: 0.76 to 1.5 encounters km^{-1} transect; high: >1.5 encounters km^{-1} transect. The amount of bamboo is given as a relative percentage of the measured trees per transect

Study site	Encounter rate class	Encounter rate (no. km^{-1})	Survey effort (km)	Bamboo (%)	Main trees Common names	Main trees Scientific names
Tamanjaya	Medium	1.09	1.82	–	–	–
Carita	Low	0	3.1	–	–	–
Bodogol	Low	0.21	4.78	0	Africa, Damar Rasamala Rasamala	*Maesobsis eminii, Agathis* spp. *Altingia excelsa* *Altingia excelsa*
Cibodas	Low	0	1.6	0		
Limbangan	Medium	1.07	2.8	20	Swamp tea tree (Kayuputih)	*Melaleuca cajuputi* Powell
Sokokembang	Low	0	5.05	0	Durian	*Durio kutejensis*
Pronojiwo	Low	0	6	2.5	Nyampo, Barus	–
Bandealit	Low	0.16	6.3	2	Jackfruit, Balsa Pulasan (Pusang)	*Artocarpus heterophyllus, Ochroma pyramidale* *Nephelium mutabile*
Cimunkat	Low	0	3.1	0		
Cipaganti	High	1.79	8.94	19.6	Fairy duster (Kaliandra) Swamp tea tree (Kayuputih) String bamboo	*Calliandra calothyrsus* Meisn. *Melaleuca cajuputi* Powell *Gigantochloa apus*
Ruksajaya	Low	0.68	5.85	8.5	String bamboo, West Indies mahogany Swamp tea tree	*Gigantochloa apus, Swietenia mahagoni* *Melaleuca cajuputi* Powell
Bantarkalong	Medium	1.23	6.47	34	String bamboo, West Indies mahogany Swamp tea tree (Kayuputhi)	*Gigantochloa apus, Swietenia mahagoni* *Melaleuca cajuputi* Powell
Sumedang	High	1.58	7.6	22	West Indies mahogany	*Swietenia mahagoni*
Ciamis	High	1.72	2.9	23	String bamboo, West Indies mahogany Swamp tea tree (Kayuputhi)	*Gigantochloa apus, Swietenia mahagoni* *Melaleuca cajuputi* Powell

macaque species in central eastern Laos (Coudrat & Nekaris 2013), it has proven to be a useful tool for analysing information on the distribution of species with limited data. Especially when it comes to rare species with very low sample sizes, Max-Ent outcompetes other modelling approaches by using regularisation to avoid over-estimates of the probability of the presence of the species (Hernandez et al. 2006, Wisz et al. 2008).

We conducted surveys in 8 out of 10 priority survey areas identified by previous MaxEnt modelling of environmental associations for *Nycticebus javanicus* (Thorn et al. 2009); in 6 (Ujung Kulon, Gunung Gede Pangrango, Meru Betiri, GunungTilu, Gunung Simpang, Gunung Sawal) (75%) *N. javanicus* were found. It was not possible to survey Gunung Halimun and Gunung Masgit Kareumbi. We did not detect *N. javanicus* around the Dieng Highlands or in Bromo Tengger Semeru National Park, although local people confirmed their presence in Bromo Tengger Semeru and had photographs of prior sightings. These findings show that Thorn et al.'s (2009) projected potential distribution, which was made using museum specimens, gave a good indication of where *N. javanicus* occurs. During the surveys, we made the most eastern sighting of a Javan slow loris on Java to date. The location of the sighting of *N. javanicus* in Meru Betiri confirms the species' distribution range to East Java.

The predicted potential distribution from our updated habitat suitability model, which is based on 56 current sightings in 13 independent localities, largely overlapped with the prediction of Thorn et al. (2009), which was based on locations of 10 museum specimens. Our suitability model suggests a larger total area size for potential Javan slow loris distribution (29 323 km^2) than the distribution Thorn at al. (2009) calculated (12 523 km^2) and predicted an extension of the suitable habitat within east Java.

Furthermore, Thorn et al. (2009) constrained their ecological niche model by restricting suggested priority areas to
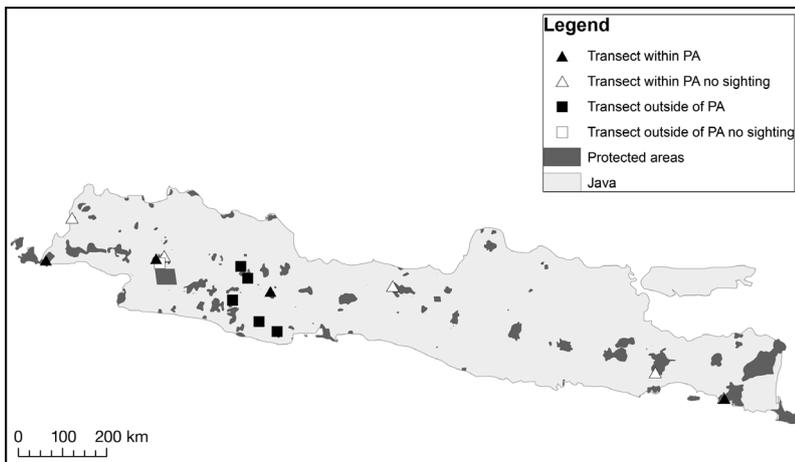
Fig. 2. Locations of surveyed areas. Black triangles indicate transects located within protected areas (PAs) on which *Nycticebus javanicus* was sighted; white triangles indicate transects within PAs with no sightings. Black squares indicate transects located outside of PAs with *N. javanicus* sightings; white squares indicate transects outside of PAs without sightings. Dark grey areas indicate the position of PAs on Java (including National Parks, Natural Reserves, and other designated area categories)
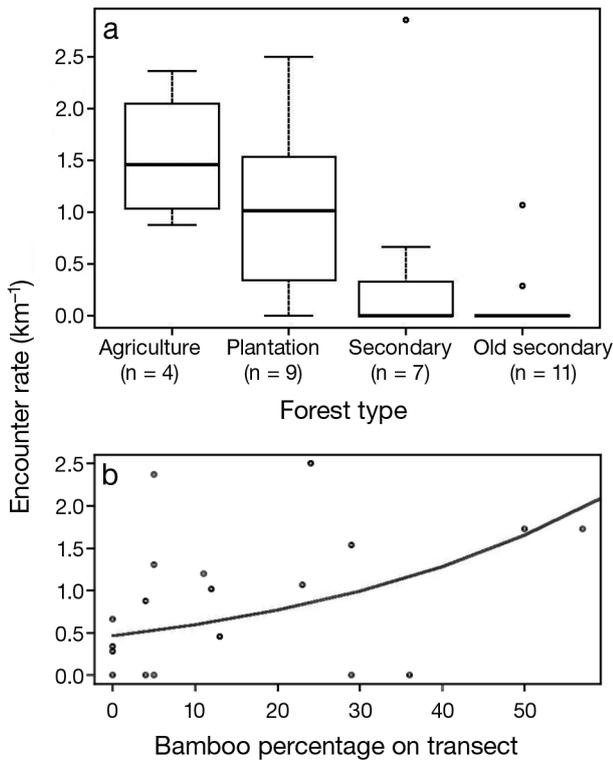
those with intact forest cover. In contrast, we revealed high encounter rates for the species in anthropogenically disturbed areas with fragmented forest cover. We made 86.5 % of the sightings of Java slow lorises outside of protected areas — in agricultural areas and forest plantations with a high presence of anthropogenic noise and logging, although the sampling effort was similar within and outside of PAs.

Of the area predicted by our model to be suitable habitat, only 20 % is protected. Together with the prediction of Thorn et al. (2009) that only 5 % of suitable habitat is located within a low-risk area, this result reveals a concerning picture. We stress the importance of ecological studies to understand if and how *N. javanicus* can persist in anthropogenically disturbed areas and the necessity of developing conservation strategies for human-altered landscapes.

We aimed to determine presence-only at each survey site. To determine densities of *N. javanicus*, further studies are required. Bromo Tengger Semeru should be revisited, since inquiries among the local people suggest the presence of *N. javanicus* in the area. East Java should also be a focus of future surveys, since distribution of lorises in that area is virtually unknown.

Fig. 3. *Nycticebus javanicus.* Number (n) of slow loris sightings (a) per kilometer across the different forest types and (b) on transects with different percentages of bamboo. The horizontal lines in the boxplot show the median encounter rates for each forest type. The top and bottom of the box show the 75th and 25th percentiles, respectively. The whiskers show the maximum values of the data
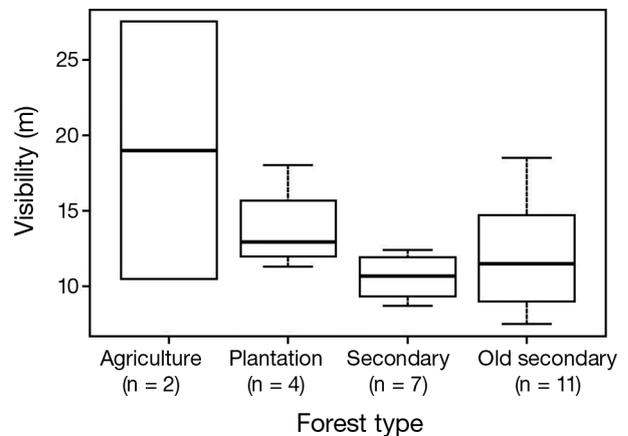

Fig. 4. Average visibility in different forest types. Although no significant difference was found, the p-values (see 'Results') indicate a tendency towards higher visibility in agricultural areas. The horizontal lines in the boxplot show the median visibility in meters for each forest type. The top and bottom of the box show the 75th and 25th percentiles, respectively. The whiskers show the maximum values of the data

Habitat preferences

The abundance of bamboo in an area was shown to be highly influential on loris presence. We suggest that at least 5% bamboo cover is needed for habitat to be suitable for *N. javanicus*. The higher encounter rate in habitat with greater bamboo cover cannot be explained by other factors, such as the visibility, which has an influence on detectability, since there was no significant difference in the visibility between sites with or without bamboo. We conclude that the presence of bamboo is of ecological value for the Javan slow loris, and suggest that the arboreal connectivity and fine branches preferred by slow lorises (Runestad 1997, Nekaris et al. 2005) are provided by areas rich in bamboo, which often occurs in large clumps with high densities (Marod et al. 1999, Giordano et al. 2009).The string bamboo *Gigantochloa apus* on Java, which was the most frequent bamboo species on transects, is a clumping bamboo species which has an average diameter of 4 to 13 cm and grows to between 15 and 30 m high (Vaupel 2005) — attributes that comply with the preferences of slow lorises (Dykyj 1980, Nekaris et al. 2005, Pliosungnoen et al. 2010). Javan slow lorises also use bamboo as sleeping and resting sites, and for social activity (P. R. Putri et al. unpubl. data, E. J. Rode pers. comm.). Furthermore, the structure of bamboo, with its thin twigs and leaves, provides excellent escape areas for the lorises to hide from predators, such as raptors and pythons (Wirdateti 2012).

In addition to the favourable structural features bamboo may provide for Javan slow lorises, it might also be beneficial from a dietary point of view. Slow lorises have been observed to forage in bamboo by gouging it to reveal insects (Starr & Nekaris 2013). To understand the role bamboo plays as habitat for the Javan slow loris we suggest further field studies to investigate the behaviour and dietary needs of the species, as this knowledge will be vital for conservation plans.

Implications for Javan slow loris conservation

The fact that the majority of our sightings were made outside PAs, in highly anthropogenically disturbed habitat, raises the question of how far the PAs on Java contribute to the conservation of *N. javanicus*. Additional studies on the habitat use of Javan slow lorises will be needed to explain the high numbers of species found in areas that have already been converted to agriculture. Furthermore, the finding

that the potential habitat for the Javan slow loris is very fragmented requires additional thought when planning extensions of PAs. Potential strategies to extend PAs could include increases in the size of forest fragments and the planning of stepping stones to connect these fragments (van Langevelde et al. 2002). For the Javan slow loris, especially, the increase in connectivity between habitat fragments plays a crucial role, since arboreal species are unable to cover large distances terrestrially due to behavioural adaptations (Nekaris & Bearder 2007).

Furthermore, because of its apparent higher abundance outside of PAs, the conservation of *N. javanicus* will be strongly dependent on the support of local communities (Lewis et al. 1990). The proximity of its habitat to human settlements makes *N. javanicus* vulnerable to illegal hunting (Rao et al. 2005). Javan slow lorises are especially imperiled due to the illegal wildlife trade and are one of the most frequently found protected primate species on illegal markets in Indonesia (Nekaris & Bearder 2007, Nekaris & Jaffe 2007). Therefore, local conservation education is vital to protect the species.

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