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Population Density and Abundance of Ebony Leaf Monkeys (*Trachypithecus auratus*) in West Bali National Park, Indonesia

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Abstract: Most of the information available on the conservation status of the ebony leaf monkey (*Trachypithecus auratus*), a species categorized as "Vulnerable" on *The IUCN Red List*, comes from studies conducted in Java. However, these findings may not be representative of other islands of the Indonesian archipelago, such as Bali. In order to estimate the density and abundance of the ebony leaf monkey population in Prapat Agung Peninsula, located in the northern part of the West Bali National Park, Indonesia, we used repeated line transect distance sampling, a standard method for census surveys of wild animal populations, including primates. The estimated group density, individual density, group size, and total population size were 0.95 group/km², 7.11 individuals/km², 7.49 individuals/group, and 422 individuals, respectively. The comparison of these values with those obtained from a previous study conducted 10 years ago in the same area and with the same method showed a marked decrease in population density and abundance as well as changes in the spatial distribution of ebony leaf monkeys. Our data suggest that such trends may be at least partially explained by anthropogenic disturbances, including illegal logging activities and habitat fragmentation. Given these alarming signs, and to better assess trends in the Balinese ebony leaf monkey populations change over time, we urge for the replication of the same survey design in the same study area, at least every five years. Such a survey effort is crucial not only to better understand the socio-ecology of ebony leaf monkeys, but also to determine conservation priorities and devise management plans related to the protection of the populations of this vulnerable primate species in Indonesia.

Key Words: line-transect, distance sampling, group density, ebony leaf monkey, conservation

Introduction

Accurate information on the status and trends of animal populations obtained from inventory and socioecological studies is a prerequisite for successful wildlife conservation programs. In order to test the outcomes of early management initiatives, and then invest further conservation efforts efficiently, wildlife decision-makers need reliable and profitable estimates of density and abundance of animal populations (Goldsmith 1991; Plumptre and Cox 2006). Among the different methods devised to generate such vital information (e.g., Struhsaker 1981a; Brockelman and Ali 1987; Whitesides *et al.* 1988), repeated line-transect distance sampling is considered a relatively simple, rapid, cost-effective, and robust method in terms of accuracy and precision (Burnham *et al.* 1980; Buckland *et al.* 1993, 2001, 2010; Cassey and Mcardle 1999; Barraclough 2000). Line-transect distance sampling proved to be particularly suitable for estimating the density and abundance of forest-dwelling, group-living primates (Defler and Pintor 1985; Chapman *et al.* 1988; García 1993; Peres 1999; Brugière and Fleury 2000; Plumptre and Cox 2006; Marshall *et al.* 2008).

In this sampling method, observers walk along a series of relatively straight transect lines, and record, for each encounter with the study objects, the perpendicular distance(s) from the line to each object detected or to the estimated center of the group formed by all objects detected (Whitesides *et al.* 1988; Hassel-Finnegan *et al.* 2008; Marshall *et al.* 2008). These distances are used to estimate a detection function (i.e. the probability that an object is detected, as a decreasing function of its distance from the line), which, in turn, allows for the calculation of the density of objects (or groups of objects) within the study area, after combining with the encounter rate, defined as the number of objects (or groups of objects) detected per unit length of line (Buckland *et al.* 1993).

Line-transect distance sampling theory is not based on the critical assumption that all objects within a specific area are detected; particularly relevant in forest habitats where the probability of detecting an object decreases rapidly with increasing distance from the observer. According to this sampling method, and with special reference to surveys of forest-dwelling primate groups, the accuracy of the density estimates is based on only four basic assumptions: 1) groups whose centers are located directly over or very close to the transect are detected with certainty (i.e. they are not missed); 2) groups are detected at their initial locations, prior to any movement in response to the observer, and are not double-counted during a census; 3) encounters are independent events; and 4) distances are measured accurately (Buckland *et al.* 1993, 2010).

There are two indigenous non-human primates in Bali, namely long-tailed macaques (*Macaca fascicularis*) and ebony leaf monkeys (*Trachypithecus auratus*) (Brandon-Jones *et al.* 2004). Balinese long-tailed macaques have been extensively studied from an ethnoprimatological perspective and for the management and conservation implications of human and non-human primate interactions, in particular at the tourist site of Pandangtegal Monkey Forest, Ubud (Wheatley 1999; Fuentes and Wolfe 2002; Malone *et al.* 2003; Fuentes and Gamerl 2005; Fuentes *et al.* 2005; Fuentes 2010). In contrast, data on the conservation status of ebony leaf monkeys are scanty.

The ebony leaf monkey (*Trachypithecus auratus*) is a threatened colobine, endemic to the islands of Java, Bali, and Lombok, Indonesia (Weitzel and Groves 1985; Nijman 2000). It is considered Vulnerable due to a past and continued population decline, estimated at more than 30% over the past 36 years (Nijman and Supriatna 2008). Its habitat has largely disappeared due to intensive logging, and its major predator is humans who hunt ebony leaf monkeys for food and commercial purposes (Djuwantoko 1994). This species is listed under CITES Appendix II, and has been protected by Indonesian law since 1999. Little is known, however, about its conservation status in a broad range of natural forest areas (cf. Nijman 2000 for a review). Most of the comprehensive studies have been conducted in a limited number of sites in Java; Pangandaran Nature Reserve (Kool 1989, 1992, 1993; Mengantara and Dirgayusa 1994; Watanabe *et al.* 1996; Mitani and Watanabe 2009), and Gunung Halimun and Ujung Kulon national parks (Gurmaya *et al.* 1994). The findings obtained from studies conducted on the species in Java may not, however, be representative of other islands of the Indonesian archipelago such as Bali (Nijman 2000).

According to Wheatley *et al.* (1993), the West Bali National Park (WBNP) may have the last viable population of ebony leaf monkeys on the island. To our knowledge, the first and only assessment of population density and abundance through line-transect distance sampling and long-term monitoring of home range size in Balinese *Trachypithecus auratus* was conducted about 10 years ago (1999–2000) in Prapat Agung Peninsula, located in the northern part of the WBNP (Vogt 2003). There are no recent data, therefore, on the population density and abundance of ebony leaf monkeys in Bali. Although relevant to socio-ecological studies and conservation issues (cf. Struhsaker 1981b), there is no information on the possible polyspecific association between ebony leaf monkeys and long-tailed macaques. Overall, due to the lack of baseline density estimates on ebony leaf monkey populations in Bali, it is difficult to make accurate inferences about the conservation status and trends of this poorly known species throughout Indonesia.

The goal of this study was to evaluate possible changes in the population density, abundance, and distribution of ebony leaf monkeys in Prapat Agung Peninsula, WBNP, by comparing current data with those obtained 10 years ago by Vogt (2003). Our specific objectives were: 1) to obtain estimates of group density, group size, total population size, and species biomass in the study area by using repeated line-transect distance sampling; 2) to provide a preliminary assessment of the spatial distribution of ebony leaf monkeys in the study area through the comparison of group abundance across the different transects surveyed; 3) to assess a possible (short-term) impact of anthropogenic disturbances on the spatial distribution of ebony leaf monkeys by a) describing the relationship between the presence/location of logging activities and the encounters with ebony leaf monkeys during our transect walks and b) complementing our transect-walk data with transect-drive data collected along the main road built across the park at the southern limit of Prapat Agung Peninsula; and 4) to calculate the rate of mixed-species spatial co-occurrence by quantifying the encounters where ebony leaf monkeys and long-tailed macaques were recorded together.

Methods

Study species

The ebony leaf monkey (*Trachypithecus auratus*), also called the ebony langur, the Javan langur and, in Bahasa Indonesia, "Javan lutung," was elevated as a species from a subspecies of *Trachypithecus cristatus* (Groves 2005). Two subspecies are recognized by Brandon-Jones *et al.* (2004), namely the West Javan ebony leaf monkey (*Trachypithecus auratus mauritius* Griffith, 1821; previously referred to as *T. a. sondaicus*) and the spangled ebony leaf monkey (*T. a. auratus* É. Geoffroy Saint-Hilaire, 1812; previously referred to as *T. a. kohlbruggei*). The study subspecies ranging in the WBNP is *T. a. auratus*.

This Asian colobine has a glossy black pelage, a head-body length of around 55 cm and a tail up to 87 cm long (Weitzel and Groves 1985; Fig. 1). The average body mass (for adult males and females) is 6.2 kg (cf. Fleagle 1999). This diurnal and arboreal primate is mainly folivorous, with a diet consisting primarily of leaves, but also including flowers, buds, fruits, bark, and insect larvae. As is characteristic of colobines, it has a specialized multi-chambered stomach with specific microorganisms in its digestive system to facilitate the breakdown of cellulose and digest plant materials efficiently (Kool 1992, 1993). Thus, this species is able to feed on a substantial amount of foliage, including mature leaves, a food relatively low in nutrients (Kool 1993).

As is typical of many other species in the genus *Trachypithecus*, the ebony leaf monkey lives in groups with a single adult male and a number of immature males, females, and juveniles. Group sizes range from 3 to more than 30 individuals, averaging 17 (Nijman 2000; Vogt 2003). The average home range size is 14 ha, and there is little overlap of the ranges of neighboring groups. Day range lengths vary from about 540 to 740 m (Vogt 2003). Ebony leaf monkeys are found in a wide variety of habitats, including primary, secondary, and remnant forests, rain, evergreen, mixed monsoon, deciduous dry, and mangrove forests, lowland, sub-montane and montane forests, as well as tree plantations and wooded savannah (Kool 1989; Djuwantoko 1994; Nijman 2000; Vogt 2003).

Study site

The West Bali National Park, locally known as Taman Nasional Bali Barat, is located on the north-western side of Bali island, Indonesia, at 8°05'S – 18°15'S and 114°25'E – 114°34'E (Fig. 2). It has an area of 19,366 ha, including the study area, Prapat Agung Peninsula (5,943 ha), which is considered a priority site for conservation in the WBNP. At its southern limit, this peninsula is cut off from the rest of the park by the main Cekik-Teluk Terima road. The park is surrounded by six villages, with a varied ethnic population. It is governed and administered by the districts of Buleleng or Jembrana. Accessibility and land use in the park is bound to a zoning system defining the degree of allowed activities (e.g., agriculture/pastoralism, religion, tourism, education, and research). The park is located in a larger area of protected reserve extending further to the east and covering approximately 77,000 ha, i.e., 10% of Bali's total land area.

The WBNP was created in 1941 with the main goal to protect one the most endangered bird species in the world, the Bali starling (*Leucopsar rothschildi*) and the last wild Indonesian bantengs (*Bos javanicus*), from which most of the Balinese cattle descend. It is now placed under the jurisdiction of the PHPA (Forest Protection Authority Indonesia, Ministry of Forestry). The park has a high biodiversity in a relatively small area, including about 160 species of birds, hawksbill turtles (*Eretmochelys imbricata*), water monitors (*Varanus salvator*), pangolins (*Manis javanicus*), large flying foxes (*Pteropus vampyrus*), black giant squirrels (*Ratufa bicolor*), rusa deer (*Cervus timorensis*), barking deer (*Muntiacus muntjak*), wild boar (*Sus scrofa*), and leopard cats (*Prionailurus bengalensis*). The long-tailed macaque (*Macaca fascicularis*) also occurs there.

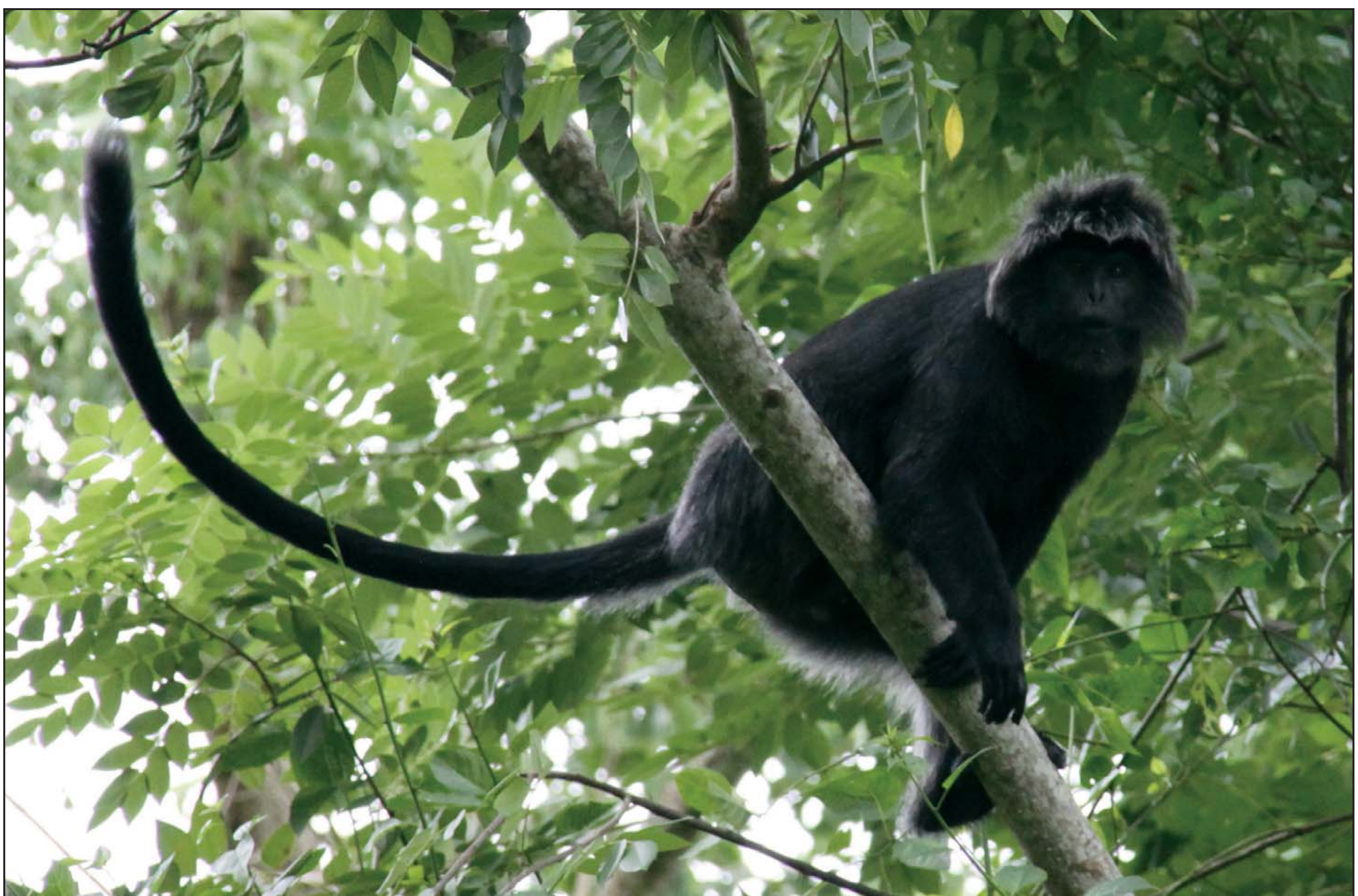

Figure 1. An adult male ebony leaf monkey (*Trachypithecus auratus auratus*) in the West Bali National Park (photo by N. Gunst)

The park comprises various habitats, including dry deciduous monsoon forests interspersed with tree plantations, fields, patches of open savannah and, on the coast, mangroves (Vogt 2003; Fig. 2). The dry season lasts from May to September and the wet season from October to April. The average annual rainfall is 1,160 mm, with a range of 972 to 1,550 mm (Vogt 2003). The topography is relatively similar throughout the study site and was unlikely to affect variability in detection distances. Thus line-transect distance sampling was appropriate to assess group density (cf. Buckland et al. 1993).

Data collection

We walked eight transects spread through the study area (Fig. 3). Each transect was 4 km long, except T7 that measured 3.5 km. Each transect was walked 10 times, giving a total distance sampled of 395 km. At least three days separated consecutive censuses of the same transect. Transects T7 and T8 were straight. T1, T2, T3, T4, T5, and T6 followed, at least partially, slightly curved pre-existing trails. Although the use of trails or paths of least resistance as transects for distance sampling was not recommended by Buckland *et al.* (1993, p.18), Hiby and Krishna (2001) argued that the curvature of the trails poses no serious theoretical or practical problems provided the radius of curvature was minimal, and a substantial proportion of detections occurred within the radius of curvature, which was the case in our study. In other words, "the fact that detection distances are generally short in […] forested habitats and that there is a natural tendency for paths and trails to avoid sharp turns suggests that, in terms of curvature, most would be suitable as transects" (Hiby and Krishna 2001: p.730). The only modification required is to record, as the detection distance, the minimum distance from the trail to the target instead of recording the perpendicular distance (Hiby and Krishna 2001).

Accordingly, when recording distances from the transect, we considered the minimum distance for T1–T6 and the perpendicular distance for T7 and T8. However, due to the collection of distance intervals (not exact distances) and the minimum curvature of our transects, it should be noted that 100% of our estimations of minimum distances were identical to perpendicular distances. Therefore, in the following, we refer to these distance measurements as perpendicular distances. We recorded perpendicular distance data by categorizing them into 13 distance intervals, namely 0–5 m, 5–10 m,

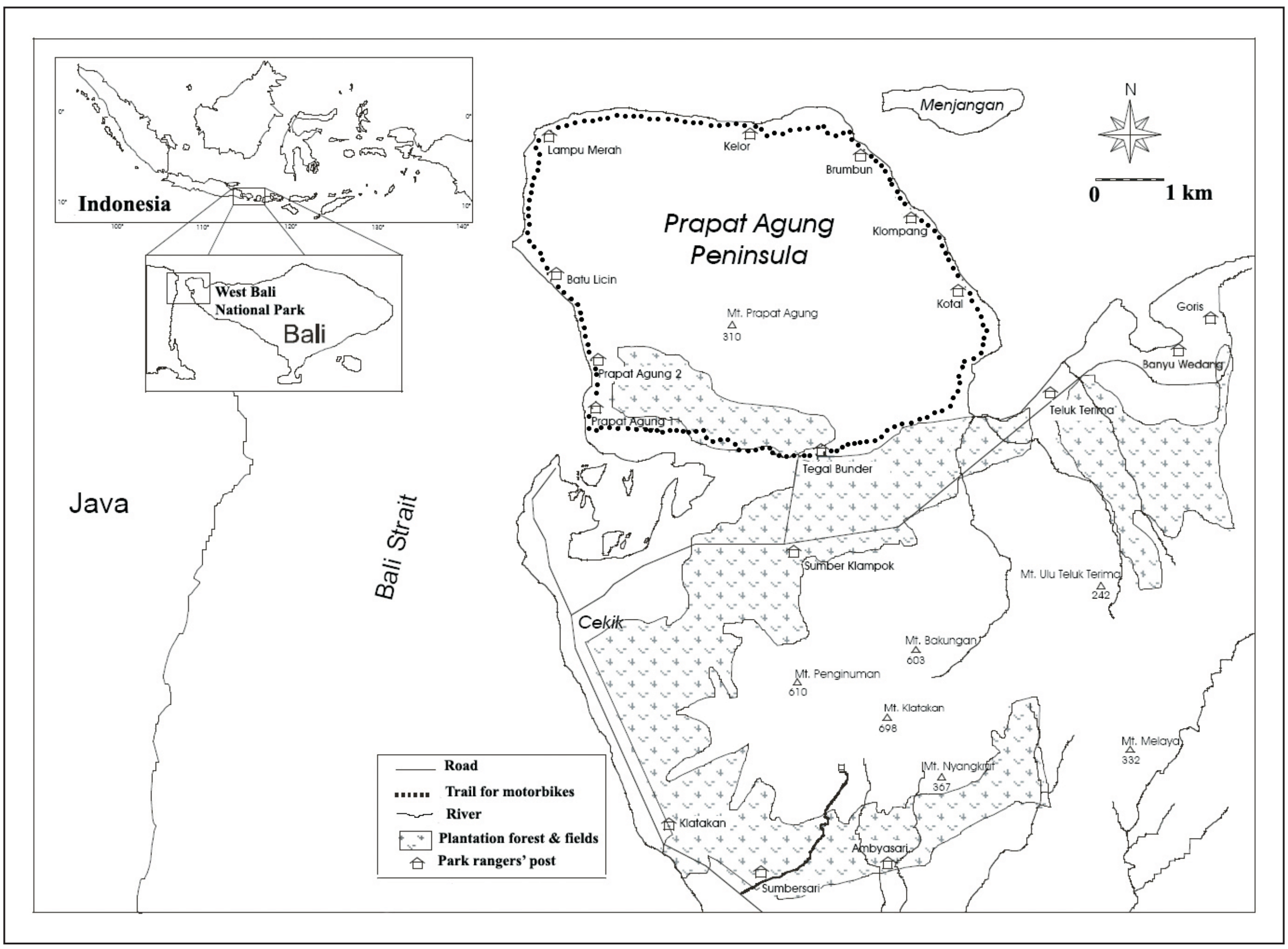

Figure 2. Map of the West Bali National Park, including the study area, Prapat Agung Peninsula (modified from Vogt 2003).

10–15 m, 15–20 m, 20–25 m, 25–30 m, 30–40 m, 40–50 m, 50–60 m, 60–70 m, 70–80 m, 80–90 m, and 90–100 m. To ensure that perpendicular distances would be estimated accurately, observers were trained on evaluating distances by eye prior to the onset of the study, and with the same distance intervals as those used during the study. Data collection started only after they reached 95% of accuracy, when compared these evaluated distance intervals with the distances measured by using a tape.

The survey was conducted by the first two authors (JBL and NG), on a daily basis (except on rainy days) between 06:30 h and 16:30 h, from February to July 2010. During our transect walks, we used the repeated line-transect distance sampling technique, recording the perpendicular distances from the transect line to the estimated center of the groups seen (Buckland *et al.* 1993, 2001). NG walked ahead on the transects, at a constant speed of 1.5 km/h (cf. Ross and Reeves 2003), looking ahead and sideways to detect study subjects, and occasionally using binoculars to determine group sizes. Following 5 m behind, JBL used a pen and paper and a Garmin GPSmap 60CSx to record, for each encounter, the following data: 1) time, 2) GPS coordinates of the detection point on the transect, 3) distance walked from the starting point, 4) the perpendicular distance, estimated by eye, from the transect line to the position on the ground directly under the center of the group of individuals, 5) general information on the (group of) individual(s) detected, such as group size and spread (defined as the largest and smallest diameters of the ellipse occupied by the group, when at least four individuals were detected), and 6) the possible co-presence of long-tailed macaques within 50 m of the center of the ebony leaf monkey group. We also recorded the presence and location of logging, whether current (i.e., taking place during our sampling) or in the past.

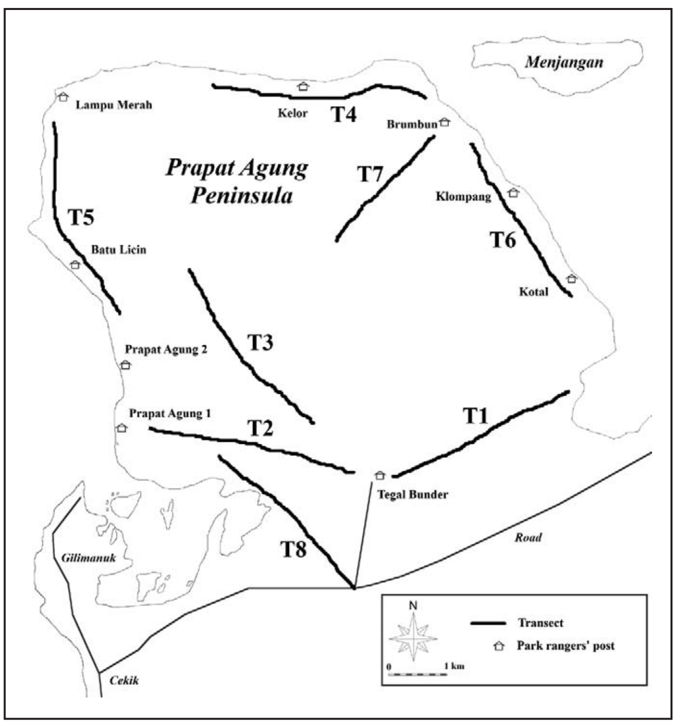

Figure 3. Map of the study area, Prapat Agung Peninsula, including the transects sampled during our survey (modified from Vogt 2003).

The main Cekik-Teluk Terima road traverses the WBNP at the southern limit of Prapat Agung Peninsula. It is lined with plantation forests and fields (Fig. 2), and we complemented our transect-walk data with surveys along this road using a motorbike. These transect drives consisted of repeatedly driving a motorbike along the road at a constant speed of 15 km/h, counting any ebony leaf monkey groups detected on either side. We made ninety one transect drives, each one 12-km long. We recorded the GPS coordinates of each encounter with ebony leaf monkeys. Although we did not use the line-transect distance sampling technique during transect drives, this additional data set gave us a better assessment of the overall abundance and spatial distribution of ebony leaf monkeys in WBNP, by taking into account, not only wild/forest-dwelling groups but also groups living in the vicinity of human settlements and infrastructure.

We recorded a total of 116 encounters during the transect walks and 13 encounters during the transect drives. An encounter was defined as the visual detection from the transect of at least one individual belonging to the study species. The number of individuals seen by the observer during each encounter was referred to as group size. After Marshall *et al.* (2008), we used the term "group" to refer to a cluster/aggregation of ebony leaf monkeys at a given moment in time, and that were located within a maximum of 100 m of each other, which reflects the maximum group spread of this species in the WBNP (Vogt, 2003). In the context of such transect sampling, we were not interested in determining whether the groups we detected were social units or temporary foraging parties/subgroups. This research adhered to the legal requirements of the Republic of Indonesia.

Data analysis

In order to provide estimates of density and abundance of ebony leaf monkeys in the study area, from data collected during transect walks, we used the computer software program Distance 6.0 (Buckland *et al.* 1993, 2001). Our sample of encounters reached the size required by this program, i.e. at least 60–80 encounters for fitting the detection function (cf. Junker *et al.* 2009).

To enter our interval distance data into Distance 6.0, we used the mid-point of each interval, namely 2.5 m, 7.5 m, 12.5 m, 17.5 m, 22.5 m, 27.5 m, 35 m, 45 m, 55 m, 65 m, 75 m, 85 m, and 95 m. We then used the data filter function of Distance 6.0 to match these mid-points with the corresponding intervals. Basic exploratory data analysis showed no particular problems in the data set, such as spiked data, heaping, evasive movement, outliers and possible gross errors. In order to avoid extra adjustment terms that might otherwise be needed to fit a long tail to the detection function (cf. Buckland *et al.* 2001, pp.151–278 153), we truncated distance data prior to analysis. We examined the distribution of distances and, even though a few groups had been detected as far as

90–100 m, we decided to use a 50 m right truncation (i.e., all observations beyond 50 m were discarded). After discarding the corresponding 6% of our observations (in agreement with the 5–10% recommended by Buckland *et al.* 2001; Thomas *et al.* 2010), 109 encounters were considered in the analyses performed by Distance 6.0.

We tested the following four combinations of regular and efficient detection function models (cf. Buckland *et al.* 1993; Thomas *et al.* 2010): 1) uniform key with cosine adjustments; 2) half-normal key with cosine adjustments; 3) half-normal key with Hermite polynomial adjustments; and 4) hazard-rate key with simple polynomial adjustments. To select the type of detection function model that best fit our data set, we used the following series of criteria (cf. Buckland *et al.* 1993, 2001; Thomas *et al.* 2010): 1) the smallest Akaike's Information Criterion (AIC) value; 2) the smallest ratio of the χ^2 goodness of fit statistic divided by its degree of freedom; 3) a few parameters to avoid large bias but not so many that precision is lost (i.e. the principle of parsimony); 4) a Delta AIC = 0; and 5) no warning messages displayed by the analysis engine. From this screening, we selected the half-normal key with cosine adjustments over alternative models.

To consider the survey effort, we used the multiplier function of Distance 6.0 to divide the density estimate by the number of visits per transect (i.e., 10 for each of the eight transects walked). The effective strip width (µ) was defined as the distance from the line at which as many groups were detected beyond µ as were missed within µ of the line (Buckland *et al.* 2001). To estimate group size, we used the mean of observed groups. Variances of encounter rate and group size were estimated analytically/empirically. The encounter rate was defined as the number of groups detected per unit length of transect, i.e., per kilometer walked (excluding those whose centers were further from the line than the truncation distance). The average distance between two consecutive encounters was the difference between two consecutive distances walked from the starting point, as measured from GPS coordinates at each encounter. Precision of estimates was measured in different ways depending on the type of analysis performed: Standard Deviation (SD), Standard Error (SE), Percentage of Coefficient of Variation (%CV, i.e., standard deviation as a percentage of the mean), or 95% Confidence Interval (95% CI).

Results

Group/individual densities, group size, total population size, and species biomass

From the detection function model that best fitted our data (half-normal key with cosine adjustments), we plotted the detection function, superimposed on the histogram showing the detection probability as a decreasing function of the distance from the transect line to the objects detected (Fig. 4). The chi-square goodness-of-fit test gives a measure of how well the model fit the data, based on a comparison of the observed and expected frequencies of observations within the distance intervals. According to Buckland *et al.* (1993), a significant goodness-of-fit statistic is a useful warning that the model might be poor, or that an assumption might be seriously violated. In contrast, our result (χ^2 = 3.22, df = 5, P = 0.666) showed that the model selected fit our data well.

The detection function allowed for the calculation of a series of statistical values (Table 1), which taken together, characterized our line-transect distance sampling survey. Table 1 shows the main estimated values for our study of the

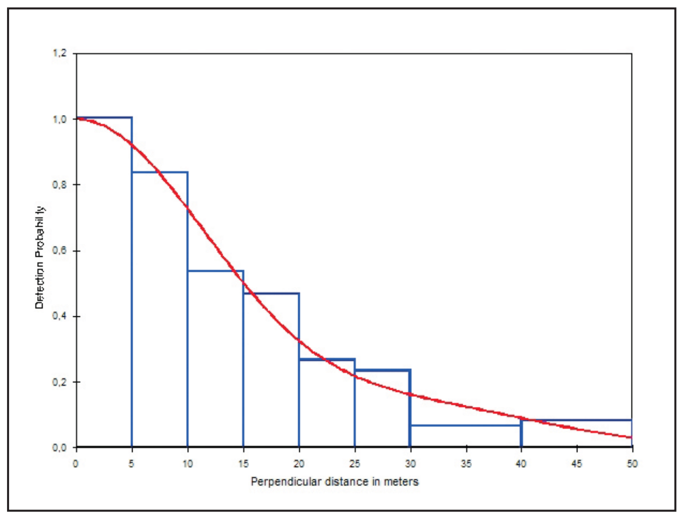

Figure 4. Histogram showing the detection probability as a function of the perpendicular distance from the transect line (interval distances), as generated by the analytical program Distance 6.0, and after right truncation distance set at 50 m. The curve represents the detection function obtained with the detection function model that best fit the data.

Table 1. Estimated values related to the population density and abundance of ebony leaf monkeys in Prapat Agung Peninsula, as obtained from Distance 6.0. Parameters were f(0): probability density function of observed distances evaluated at 0 m, ESW: effective strip width (in meters), ER: encounter rate, DS: estimate of density of groups (number per km²), D: estimate of density of individuals (number per km²), E(S): estimate of expected value (mean) of group size, and N: estimate of number of individuals in the study area. Precision measurements were SE: standard error, %CV: coefficient of variation (i.e. standard deviation as a percentage of the mean), df: degree of freedom, and 95% CI: 95% confidence interval.

Parameter	Estimate	SE	%CV	df	95% CI	
f(0)	0.55E-01	-	10.05	107	0.45E-01	0.67E-01
ESW	18.25	-	10.05	107	14.96	22.26
ER	0.35	-	9.87	79	0.28	0.42
DS	0.95	0.13	14.08	-	0.72	1.25
D	7.11	1.09	15.37	-	5.26	9.60
E(S)	7.49	0.46	6.17	108	6.63	8.47
N	422	64.87	15.37	-	313	571

population density and abundance of ebony leaf monkeys in Prapat Agung Peninsula, including the probability density function of observed distances evaluated at 0 m, the effective strip width, the encounter rate, the density of groups, the density of individuals, the mean group size, and the number of individuals in the study area. Based on the total population size estimate (422 individuals), the mean body mass (6.2 kg; cf. Fleagle 1999), and the surface area of Prapat Agung Peninsula (59.43 km²), the ebony leaf monkey biomass estimate in the study area was 44.02 kg/km².

Spatial distribution of ebony leaf monkeys in Prapat Agung Peninsula

Table 2 shows the group abundance and size in the different transects sampled. This preliminary assessment of the spatial distribution of ebony leaf monkeys within the study area showed similar numbers of group encounters and group sizes in most transects (total average: 0.35 group detected/km), except T1 with relatively high values (0.65 group detected/km), and T3 with relatively low values (0.10 group detected/km). Groups were not only notably separated in space (overall mean distance between two consecutive groups = 1.11 ± 0.78 km; cf. Table 2) but also highly clustered, with 80 out of 96 encounters (i.e., 83.3%) showing group spreads between 20 and 50 m in diameter. The maximum group spread was 100 × 80 m, for only two encounters.

Impact of anthropogenic disturbances on the spatial distribution of ebony leaf monkeys

During our transect walks, we recorded 26 spots where there was active or past logging. They were all in the southern part of Prapat Agung Peninsula (four spots on T1, eight on T2, nine on T3, and five on T8). Nineteen were active and seven showed signs of logging at least several weeks before our observations. Logging significantly decreased the encounter rate (Mann-Whitney U test: $z = 4.94$, $p < 0.001$). We never found ebony leaf monkeys within 1.5 km of places which were being logged, whereas we recorded 11 encounters within 0.1 km of spots where there had been logging in the past.

In the motorbike censuses, we saw ebony leaf monkeys 13 times. The sightings were highly clustered in a 220-m-long stretch along the Cekik-Teluk Terima road, half-way between Cekik and Sumber Klampok (cf. Fig. 2). Unlike elsewhere along the road, this stretch had large trees with stout branches extending over the road, which suggests it may be a dispersal corridor between two parts of a group's home range separated by agricultural fields and pastoral areas. Based on individual observations, and given the little overlap of home range found in these ebony leaf monkeys (cf. Vogt, 2003), we believe that these encounters were all of the same social group.

Rate of mixed-species spatial co-occurrence

One or a group of long-tailed macaques was found within 50 m of one or a group of ebony leaf monkeys 12 times in 116 encounters (twice on T1, seven times on T2, twice on T4, and once on T5), i.e., a rate of mixed-species spatial co-occurrence of 10.3%. In all cases, the long-tailed macaques were on the ground, whereas the ebony leaf monkeys were in the trees. In three encounters (one during a transect walk, which was not considered in our distance analyses, and two during reconnaissance walks), long-tailed macaques gave alarm calls as we approached, which resulted in ebony leaf monkeys moving away from us. We saw no other types of interaction between the two species.

Table 2. Number, mean, and relative location of groups and individuals detected in the different transects sampled, with their corresponding types of vegetation (DDMF: dry deciduous monsoon forest, MG: mangrove, PF: plantation forest, SV: savannah).

Transect	Vegetation	Length (km)	No. of visits	Total number of groups detected (cumulative over visits)	Mean number of groups detected/km	Total number of individuals detected (cumulative over visits)	Mean ± SD (min-max) number of individuals detected per group	Mean ± SD (min-max) number of individuals detected per transect walked	Mean ± SD (min-max) distance (km) between two consecutive groups
T1	DDMF/MG/PF	4	10	26	0.65	240	9.2 ± 7.2 (1–28)	26.7 ± 21.2 (5–64)	0.72 ± 0.36 (0.41–1.55)
T2	DDMF/MG/PF	4	10	13	0.33	107	8.2 ± 4.9 (1–20)	15.3 ± 6.5 (8–24)	1.42 ± 0.83 (0.42–2.54)
T3	DDMF/PF	4	10	4	0.10	24	6.0 ± 3.6 (1–9)	6.0 ± 3.6 (1–9)	n/a
T4	DDMF/MG/SV	4	10	19	0.47	115	6.1 ± 3.1 (1–12)	14.4 ± 9.1 (5–29)	1.17 ± 0.64 (0.43–2.57)
T5	DDMF/PF	4	10	12	0.30	68	5.7 ± 4.8 (1–17)	7.6 ± 6.6 (2–20)	0.52 ± 0.03 (0.50–0.55)
T6	DDMF/MG/SV	4	10	12	0.30	86	7.2 ± 2.9 (3–13)	10.7 ± 4.4 (4–17)	1.31 ± 0.86 (0.71–2.83
T7	DDMF/SV	3.5	10	12	0.34	107	8.9 ± 3.5 (5–15)	13.4 ± 7.5 (6–28)	0.94 ± 0.60 (0.40–1.66)
T8	DDMF/MG/PF/SV	4	10	11	0.28	70	6.4 ± 1.4 (5–9)	10.0 ± 4.5 (5–15)	2.44 ± 1.25 (0.58–3.19)
Total		31.5	10	109	0.35	817	7.5 ± 4.8 (1–28)	13.6 ± 11.4 (1–64)	1.11 ± 0.78 (0.40–3.19)

Discussion

Validity of our line-transect distance sampling design and analysis

Theoretically, it is preferable to sample a series of randomly distributed transects within a given survey area, rather than along pre-existing trails. A permanent human presence may affect the animals' behavior and spatial distribution, and consequently animal density estimates may be biased (Buckland *et al.* 2010). Although we were completely aware of these recommendations in terms of survey design before selecting our transects (two straight transects and six that followed slightly curved pre-existing trails), we emphasize two arguments in support of our methodology.

First, the shape of the detection probability histogram (Fig. 4) suggests that, although several transects were placed along pre-existing trails, a relatively high proportion of encounters occurred directly on or near to the transects (perpendicular distance: 0–5 m), and animals did not always move away from the approaching observer. Second, in practice, non-randomized designs, including transects along pre-existing trails, are frequent in primate surveys (Hiby and Krishna 2001; Buckland *et al.* 2010). As long as the number of these transects is sufficient with regard to the survey region, the design remains acceptable (Buckland *et al.* 2001). In this respect, we claim that, given the relatively small size of the study area, the number of transects (i.e., eight) was sufficient to ensure that they did not pass through areas with atypical densities. Moreover, our transects were widely distributed and regularly spaced.

It may also be argued that laying transects along pre-existing trails means that the habitat might not be sampled in a representative manner, because such trails are often placed either on ridges or along waterways, and thus over- or under-sampling some habitats. In response to this argument, we claim that all the types of habitats present on Prapat Agung Peninsula were sampled by our transects (cf. Table 2), which were therefore representative of the entire study area. Our survey design provided a good coverage of the study area, which increases the accuracy and precision of estimates.

We believe that our sampling conditions did not violate any of the four key assumptions on which distance sampling methods rely (cf. Buckland *et al.* 2001). First, owing to the large size of ebony leaf monkeys and the relatively large number of individuals per group, we were very unlikely to miss groups located directly over the transects. Second, in the vast majority of cases, we were cautious enough not to make the study subjects move away before we detected them in their initial positions. Moreover, our line transect design and our average walking speed (faster than the animals' travel speed) prevented us from possible double counts. Third, our result on the average distance between two consecutive encounters (cf. Table 2) is consistent with the small home range overlap that Vogt (2003) reported for this species, and strongly suggests that our encounters were independent events. Fourth, due to pre-study training, observers were unlikely to introduce biases related to distance measurement errors.

Finally, during our survey, we obtained well over the minimum number of detections (i.e., 60–80) necessary for fitting the detection function (Barraclough 2000). Our testing of different combinations of possible detection function models and subsequent adjustments provided very similar estimates, which is an additional guarantee of high quality survey information. Overall, we believe our survey design and data on the abundance of ebony leaf monkeys in Prapat Agung Peninsula, West Bali National Park, were of sufficient quality to produce reliable estimates of their density in the study area.

Group/individual densities, group size, total population size, and species biomass

In order to evaluate possible changes in the population density, abundance, and distribution of ebony leaf monkeys in Prapat Agung Peninsula, WBNP, we compared our results with those obtained from the only previous survey on this species, in the same study area, conducted 10 years before (1999–2000), and through repeated line-transect distance sampling (Vogt 2003). All the estimated values provided by the current study were markedly lower than those found by Vogt (2003): 1) the estimated group density was 0.95 groups/km² in 2010 versus 1.94 groups/km² in 2000 — a 51% decrease; 2) the estimated individual density was 7.11 individuals/km² in 2010 versus 33.23 individuals/km² in 2000 — a 79% decrease; 3) the estimated number of individuals on Prapat Agung Peninsula was 422 individuals in 2010 versus 1,972 in 2000 (calculated from Vogt 2003, with a study area of 59.43 km²) — a 79% decrease; 4) the estimated group size was 7.49 individuals/group in 2010 versus 17.13 in 2000 — a 56% decrease; and 5) the estimated ebony leaf monkey biomass was 44.02 kg/km² in 2010 versus 191.42 kg/km² in 2000 — a 77% decrease.

We acknowledge that we may have underestimated the individual density, because the group size estimates found from our transects (7.49 individuals/group) underestimated by 56% the mean group size found for this species, based on a long-term monitoring of 13 groups (mean: 17.13 individuals, range: 3–30; cf. Nijman 2000; Vogt 2003). This difference is consistent with other studies showing that the line-transect sampling method systematically underestimates the mean group size of forest-dwelling monkeys because of relatively poor visibility (Green 1978; Defler and Pintor 1985; Simmen *et al.* 1998; Brugière and Fleury 2000). This discrepancy simply suggests that much caution is required when discussing results on group size obtained from distance surveys. They should be regarded as preliminary, and further supported with long-term follows of particular groups (Plumptre and Reynolds 1994; Brugière and Fleury 2000; Plumptre 2000). One advantage of distance sampling, however, is that the estimation of population density can still be accurate even when only a relatively small percentage of individuals (possibly as few as 10–30%) are detected within the sampled area (Barraclough 2000).

It may also be argued that our study period (during the wet season) could at least partially explain our lower values. First, group sizes of ebony leaf monkeys in Java vary according to the climatic conditions of the area, with smaller groups found in areas where the wet season is more pronounced (Nijman 2000). Second, there is no doubt that visibility during the wet season is not as good as it is during the dry season. Seasonal variation in visibility is not likely to account for such differences, however, because the line transect survey by Vogt (2003) was also conducted during the wet season. Moreover, although visibility can be assumed to affect the assessment of individual density more than the assessment of group density, there was also a marked difference between the estimated group densities found in the two surveys.

Overall, the direct comparison of our current data with findings obtained 10 years ago in Prapat Agung Peninsula with the exact same method leads to the conclusion that there has been a significant decrease in the population density and some changes in the spatial distribution of ebony leaf monkeys. The individual density found in our study is also lower than that found in different sites in Java, which range from 20 to 75 individuals/km² (Supriatna *et al.* 1988; Nijman and van Balen 1998; Nijman 2000). It should be noted, however, that these sites tend to be selected because of the local relative abundance of ebony leaf monkeys, which suggest that a more typical density may be in the lower range (Nijman 2000).

Spatial distribution of ebony leaf monkeys in Prapat Agung Peninsula

The comparison of group abundance across the different transects surveyed (Table 2) suggests that the spatial distribution of ebony leaf monkeys in Prapat Agung Peninsula was not entirely uniform. This result may, at least in part, be explained by the impact of anthropogenic disturbance (see below for details). Our results on intergroup distances and group spread were consistent with previous findings for this species, showing highly clustered groups with little home range overlap (Vogt 2003).

Regarding the comparison of the spatial distribution over time, it should be noted that the results obtained by Vogt (2003) were drawn from five transects (T1, T2, T3, and T4 were similar to those sampled in our study, whereas Vogt's fifth transect was in the central peninsula, between T3 and T7). When comparing the mean number of groups detected per km of transect, we found marked differences for T1 and T3, and similar values for T2 and T4: 1) 0.65 groups/km was detected on T1 in 2010 versus 0.05 groups/km in 2000, 2) 0.33 groups/km was detected on T2 in 2010 versus 0.27 groups/km in 2000, 3) 0.10 groups/km was detected on T3 in 2010 versus 0.20 groups/km in 2000, and 4) 0.47 groups/km was detected on T4 in 2010 versus 0.46 groups/km in 2000. The WBNP may have the last viable population of ebony leaf monkeys in Bali (Wheatley *et al.* 1993). The species might also be present, however, in the park's eastern extension and the mountainous interior of Bali island (Nijman 2000).

Impact of anthropogenic disturbances on the spatial distribution of ebony leaf monkeys

Although our preliminary data would need to be supported by a larger sample collected over a several-year period, they suggest a negative effect of logging activities on the presence of ebony leaf monkeys in the vicinity. However, as suggested by their presence around past logging sites, this effect seems temporary, and the monkeys are likely to reoccupy logged areas after a certain delay that remains to be determined by a long-term study. This is consistent with previous research showing that the dynamics of re-occupation of logged areas by most primates is generally slow (Chapman *et al.* 2005). Our finding of the occasional presence of usually cryptic ebony leaf monkeys along a main road with heavy traffic and lined with plantation forests and agricultural fields emphasizes the need to preserve dispersal corridors for this threatened species living in such a fragmented habitat. The main threats currently faced by the Balinese ebony leaf monkeys are continuing habitat loss, degradation, fragmentation, as well as indirect negative impacts from illegal hunting for the Bali starlings (Vogt 2003). Although this species is able to cope with a certain degree of habitat disturbance, some populations may find themselves cornered in small forest remnants, with no possibilities to leave, because of the absence of dispersal corridors and adjacent forest patches (Nijman 2000). In the longer term, the population of ebony leaf monkeys ranging in Prapat Agung Peninsula may face a risk of genetic isolation from other populations in Bali.

Rate of mixed-species spatial co-occurrence

Although line-transect sampling is not typically used to quantify primate polyspecific associations, our data show that ebony leaf monkeys and long-tailed macaques can be spatially associated. The non-negligible rate of co-occurrence, the distinct vertical distribution of the two species, and the few instances of anti-predator benefits for ebony leaf monkeys are reminiscent of true polyspecific associations, defined as associations between two or more species that involve behavioral changes by at least one of the participating species (Strier 2003). More data from long-term group monitoring are needed, however, to clarify whether such co-occurrence was a matter of chance or the result of a true polyspecific association.

Future directions

Overall, this project provided new, broad, and accurate information on the density, abundance, geographical distribution, and ecology of ebony leaf monkeys in Prapat Agung Peninsula, WBNP; data that are necessary to assess the current status of this species, implement conservation priorities, and create management plans for the *Trachypithecus auratus* populations on a larger scale. We believe the comparison of our demographic, geographical, and ecological data with findings obtained in Java (Kool 1989, 1992, 1993; Gurmaya *et al.* 1994; Mengantara and Dirgayusa 1994; Watanabe *et al.* 1996; Mitani and Watanabe 2009) will contribute to provide a comprehensive assessment of the conservation status of *Trachypithecus auratus* in Indonesia.

We hope that: 1) our geographic database will be considered by park managers and other researchers in their decision-making for a better protection of the species and a more accurate assessment of the species' conservation status; 2) our results on the occurrence of illegal logging in Prapat Agung Peninsula will be used by the park authorities to prevent, as far as possible, such a detrimental impact; and 3) our findings will provide a baseline for future replicable census surveys of ebony leaf monkeys in the same area. Providing accurate descriptions of this species' status and demographic trends, long-term inventory studies are crucial for the decisions of wildlife managers in ways of preventing such population decrease tendencies. Our quantification of the precision of abundance estimates may also allow the comparison of our results with those obtained from alternative census methods, such as complete count surveys or methods combining point census and group follows (Harcourt and Fossey 1981; McNeilage *et al.* 2001; Hanya *et al.* 2003).

In the foreseeable future, several focused studies could be conducted in the WBNP, as a direct follow-up on the current research/conservation survey. We suggest four main directions for future efforts devoted to the monitoring of the population of ebony leaf monkeys in the WBNP. First, to assess trends in rates of population change over time, we urge for the replication of the exact same survey design at least every five years. Second, to evaluate seasonal variation in the distribution/movements of ebony leaf monkeys, our findings should be compared with those obtained from an identical survey that would be conducted during the dry season.

Third, to estimate how the population size may be affected by environmental or anthropogenic factors, future studies should stratify the study area (or the entire WBNP) and conduct distinct line-transect sampling within each major habitat type (plantation forest, secondary forest, savannah, human settlements, agricultural/pastoral areas, roads, etc.). Such anthropogenic factors include the subsistence activities of local villagers living inside the park, religious activities (e.g., Hindu gatherings in local temples located in the park), and tourist activities (e.g., guided-tours) on Prapat Agung Peninsula. Our preliminary data suggest that the occurrence and prevalence of illegal logging should be considered in these analyses. Fourth, to assess the population genetic structure of Balinese ebony leaf monkeys, DNA analysis could be conducted from the fecal samples collected in different groups. In the long term, information on genetic variation within and between groups, particularly on a small island such as Bali, could be used to assess the viability of the populations studied (Frankham 1996). Such survey efforts are crucial not only for a better understanding of the socioecology of ebony leaf monkeys, but also to determine conservation priorities, devise management plans, and diversify local education programs related to the protection of the populations of this vulnerable primate species in Indonesia.

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