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Have Habitat Loss and Fragmentation Affected the Social Organization of the Western Purple-faced Langur (*Semnopithecus vetulus nestor*)?

Surendranie J. Cabral[1,2], Amila P. Sumanapala[2], Devaka K. Weerakoon[1], Sarath W. Kotagama[1] and Rasanayagam Rudran[3]

[1]*Department of Zoology and Environmental Sciences, University of Colombo, Colombo, Sri Lanka*
[2]*Foundation for Nature Conservation and Preservation, Panadura, Sri Lanka*
[3]*Smithsonian Conservation Biology Institute, Washington, DC, USA*

Abstract: The majority of Sri Lanka's endemic and Critically Endangered western purple-faced langurs, *Semnopithecus vetulus nestor*, inhabit fragmented and densely populated areas. Habitat loss and fragmentation resulting from agriculture and development may have an impact on the purple-faced langur's social organization and create challenges to their survival. To evaluate this question we collected data on group size and age-sex composition of these langurs in two human-modified (non-forest) landscapes (in Pannipitiya and Malabe) and one forest landscape (in Dombagaskanda Forest Reserve), using the total count method. A total of 30 groups were counted, of which 15 and seven were from Pannipitiya and Malabe, respectively, and eight were from Domabagaskanda Forest Reserve. Groups occupying non-forest areas had a greater variation in group size relative to the mean than groups in the forest. The largest of the non-forest groups may have been an aggregation of langurs that were displaced from their territories due to habitat destruction or it may have resulted from male turnover. The dispersal of langurs may be limited by lack of canopy connection in non-forest habitats. More systematic investigation of density and distribution at the landscape level is needed for the proper management of the remaining populations of these Critically Endangered langurs.

Key words: Purple-faced langur, group size and composition, habitat loss and fragmentation, human-monkey conflict

Introduction

Anthropogenic activities resulting in habitat alteration affect the behavior and social organization of primates, and create numerous challenges to their survival (Bishop *et al.* 1981; Sterck 1999; Schwitzer *et al.* 2011). Dispersal, for example, is important for maintenance of the social structure and a healthy gene pool (Bishop *et al*. 1981; Melnick *et al.* 1984; Melnick and Hoelzer 1992; Pope 1992), and habitat loss and fragmentation due to agriculture and development resulting in population isolation can impede it (Banks *et al.* 2007; Fischer and Lindenmayer 2007; Arroyo-Rodríguez and Dias 2010). Habitat fragmentation can also directly influence food availability via edge effects and habitat degradation (Arroyo-Rodriguez and Mandujano 2009). Poor habitat conditions in fragmented habitats can cause physiological stress, affecting health, fertility and survival (Martínez-Mota *et al.* 2007; Rangel-Negrín *et al*. 2009). Habitat quality and connectivity in fragmented landscapes also affect the group size, density and distribution (Eisenberg *et al*. 1972; Siex and Struhsaker 1999; Onderdonk and Chapman 2000; Marshall *et al.* 2005; Anzures-Dadda and Manson 2007).

A substantial proportion of the population of the western purple-faced langur *Semnopithecus vetulus nestor* Bennett, 1833, which is endemic to Sri Lanka, now live in human-modified, fragmented landscapes (Rudran 2007; Parker *et al*. 2008). One of four recognized subspecies of the purple-faced langur, *S. v. nestor* occurs in western Sri Lanka (Fig. 1), originally from north of the Kalu River to Giriulla and Polgahawela (Rudran 2007). In this region, there are only few and sparsely distributed forest patches (Gunatilleke and Gunatilleke 1990), and the remaining habitats are experiencing accelerated development, urbanization, agricultural expansion, and high human population density (Sri Lanka, MOFE 1999; Sri Lanka, Department of Census and Statistics 2012). Purple-faced langurs are folivorous, with their diet supplemented by flowers, seeds and fruits, and are almost entirely arboreal (Rudran 1970; Dela 1998, 2007). Their populations are declining as their food sources are diminished and canopy connections are lost, limiting their travel routes (Molur *et al.* 2003; Dela 2011). The western purple-faced langur is classified as Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List (Dittus *et al*. 2008), and since 2004 has been listed among

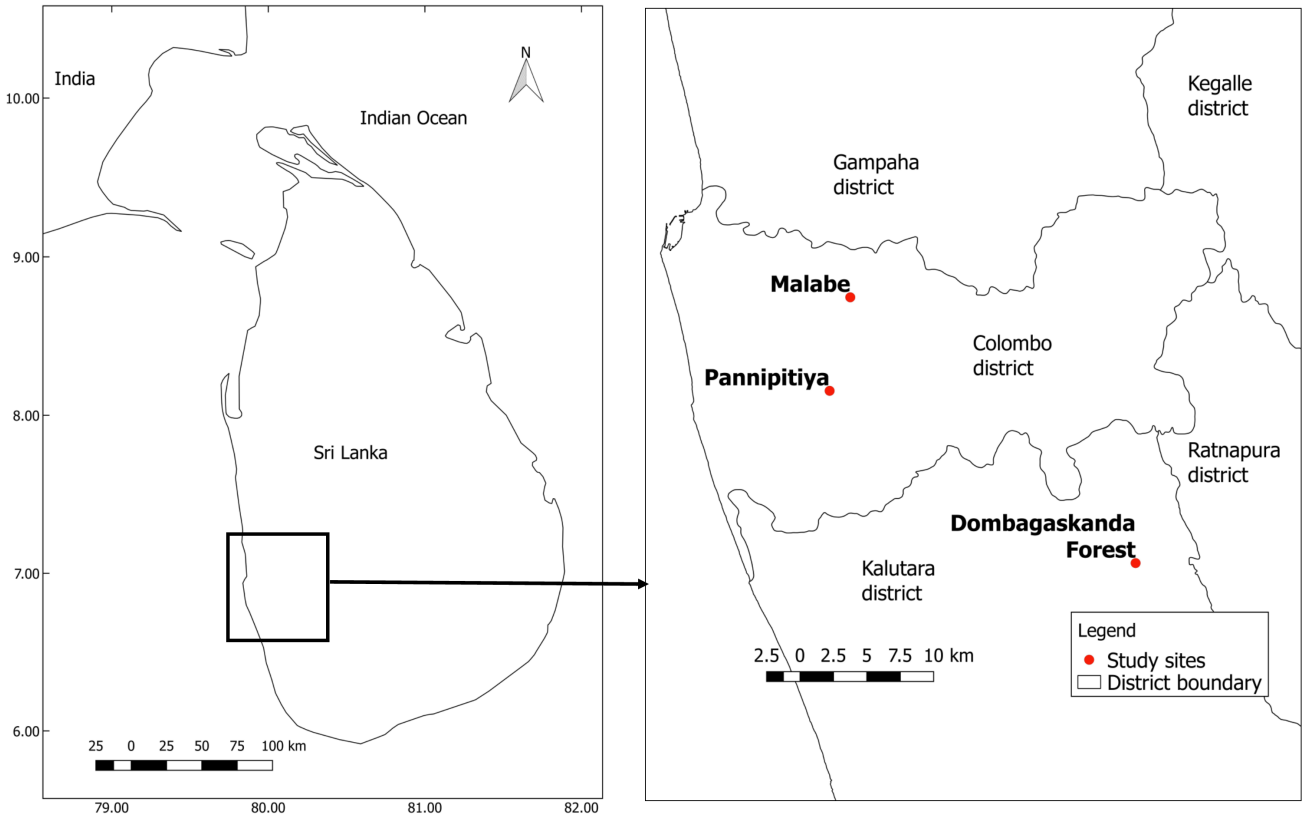

Figure 1. Location of the three study sites in Sri Lanka.

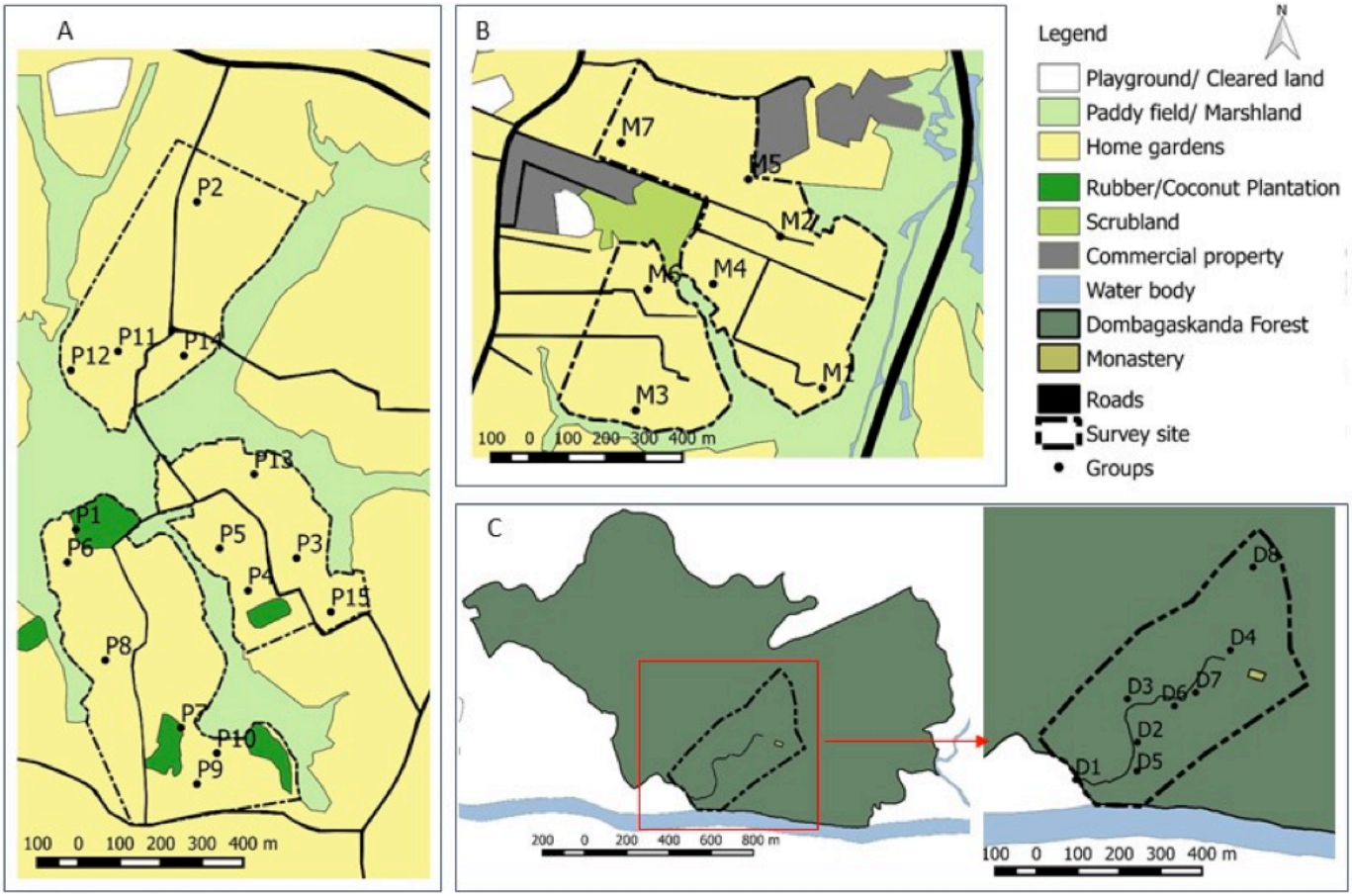

Figure 2. Distribution of groups observed in the survey sites. A − Pannipitiya, B − Malabe, C− Dombagaskanda Forest Reserve. Group name (group size): P1 (12), P2 (10), P3 (13), P4 (8), P5 (14), P6 (4), P7 (26), P8 (11), P9 (9), P10 (7), P11(12), P12 (3), P13 (6), P14 (11), P15 (6), M1 (8), M2 (6), (M3(14), M4 (13), M5 (9), M6 (3), M7 (9), D1 (4), D2 (6), D3 (9), D4 (11), D5 (6), D6 (11), D7 (10), D8 (8)

the world's 25 most endangered primates (Rudran and Cabral 2017). Further, since these langurs damage crops and property, they are considered to be pests in the habitats they share with people (Rudran 2007; Nahallage *et al.* 2008; Dela 2011; Cabral *et al.* 2018).

The typical reproductive unit of the purple-faced langur is the harem, in which groups comprise one adult male and many females (Rudran 1973; Manley 1984), although groups with two adult males have also been observed (Rudran 1970; Dela 1998). In addition there are male groups, which are also referred to as "predominantly-male groups" as they sometimes include one or more immature females (Manley 1984; Rudran 2013), and there are solitary animals or small groups of up to three animals traveling together but with no distinct territory (Manley 1978). The uni-male group structure is maintained by males leaving their natal groups as they reach adulthood to become solitary or join predominantly-male groups. They may later take over reproductive groups by evicting the existing adult male (Rudran 1970,1973; Manley 1984). This type of male dispersal may be limited in fragmented, human-modified landscapes, with discontinuous canopy connections affecting the social interactions, dispersal and viability of these langur populations in the long term (Banks *et al.* 2007). Given the adverse impacts of habitat loss and fragmentation on primate social organization, the aim of this study was to evaluate whether continued survival of the Critically Endangered western purple-faced langur is in jeopardy, as indicated by their group size and age-sex composition in forest and non-forest landscapes.

Methods

Study sites

Our study was conducted in two human-modified (non-forest) landscapes; Pannipitiya (6°50'9.34"N, 79°57'19.37"E) and Malabe (6°54'49.18"N, 79°58'41.32"E), both suburbs of Colombo, the country's capital, and in a forest landscape in Dombagaskanda Forest Reserve (6°43'32.35"N, 80° 9'31.66"E) (Fig. 2). Our survey sites in Pannipitiya (survey area = 62 ha) and Malabe (survey area = 45 ha) consisted of home gardens, rubber plantations, paddy fields, cleared land, and small patches of scrubland at an elevation of 5−30 m above sea level (Fig. 2). Our forest study site (survey area = 20 ha) in Dombagaskanda Forest Reserve, which is approximately 1.9 km^2 (Fig. 2) is a tropical lowland rain forest, bordered by the Kalu River from the south and 20−200 m above sea level (Ranasinghe and Ratnayake 1992).

Data collection

Our study was carried out from June to August 2012, during the south-west monsoon season (Sri Lanka, Department of Meteorology 2012). In each study site, effort was taken to find as many groups as we could, and census them during the study period. Surveys were conducted by two observers, on foot, from 06:00–11:00 and 14:00–18:00. Once a group was encountered it was followed and observed as long as necessary to be certain that all individuals were seen and counted. These searches were facilitated by visual cues and auditory cues such as the loud whoop calls of adult males. In non-forest areas local residents also helped us to locate langur groups. The age and sex of individuals were noted, and the group's location was recorded using a hand-held GPS unit. The age-sex criteria used for this study was based on Rudran (1970), Phillips (1981) and Dela (1998) as follows.

Sex differences: the adult female is smaller than the male, has shorter whiskers, and a characteristic triangular white patch on the pubic area.

Newborns and infants: less than 12 months, always seated on an adult female's lap, long periods of sleep, newborns have a paler pelage and crown, have a fine soft coat which is gradually replaced by the permanent coat. They are carried by the mother.

Juveniles: resemble adults in miniature, and show independent movement during travel.

Sub-adults: body size of the male is similar to the adult female, the size of the female is variable. They show more independence than juveniles.

Adults: external genitalia of males are well visible. Adult males emit the whoop vocalization, are more robust, and the canines fully erupted. Adult females have given birth at least once, and the nipples and clitoris are prominent.

Repeat counts of group size and composition of each group were obtained by revisiting the group on the same day or on a different day. The most reliable count or the maximum count was taken as the group size. As these animals are territorial and inhabit a defined home range, locating and identifying a group distinct from another during later visits was done based on its location and age-sex composition. On most occasions we detected neighboring groups simultaneously, which was helpful in distinguishing them apart.

Data were collected during 33 days in the three study sites (Pannipitiya: n = 18, Malabe: n = 7, Domabagskanda: n = 8). The number of groups encountered each day ranged from 1−4 (1.6 ±0.8) and 1−3 (1.4 ±0.8) for Pannipitiya and Malabe, respectively. The number of repeat counts obtained per group ranged from 2−4 and 2−3 for Pannipitiya and Malabe, respectively. Total observation hours per group in non-forest habitats ranged from 4−18 hours. Number of groups encountered per day at Dombagaskanda Forest Reserve varied from 0−4 (2.7 ±1.4), and the number of repeat counts obtained ranged from 2−4. Total observation hours per forest group ranged from 2−6 hours.

Distribution maps of the groups counted were generated using Quantum Geographical Information Systems software (QGIS Development Team 2015) using the GPS points collected during field work. Land use maps were created by digitizing satellite imagery freely available through the GIS software. The Dombagaskanda Forest Reserve boundary map was obtained from the Survey Department of Sri Lanka in 2012. R statistical software (R Core Team 2014) was used for data analysis. The Kruskal-Wallis Test (5% significance level) was used to compare the group sizes and composition

Table 1. Summary of groups counted at all study sites.

Field site			Pannipitiya			Malabe			Dombagaskanda Forest Reserve			Total		
Animals counted			153			64			67			284		
Lone males			1			2			2			5		
Population in uni-male groups			152			62			65			279		
Total number of groups			15			7			8			30		
Population density (ha^{-1})			2.47			1.42			3.35			2.24		
Group density (ha^{-1})			0.24			0.16			0.40			0.24		
Mean group size (CV)			10.1 ±5.5 (54.2)			8.9 ±3.8 (42.96)			8.1 ±2.3 (31.86)			9.3 ±4.4 (48.06)		
Range			3−26			4−14			4−11			3−26		
			%	**Range**	**Mean (CV)**	**%**	**Range**	**Mean (CV)**	**%**	**Range**	**Mean (CV)**	**%**	**Range**	**Mean (CV)**
Population of uni-male groups	Adult	M	9.9	1	1	11.3	1	1	12.3	1	1	10.8	1	1
		F	46.7	1−8	4.7±2.3 (49.5)	48.4	1−6	4.3±1.9 (44.1)	47.7	2−5	3.9±1.4 (35.1)	47.3	1−8	4.4±2.0 (45.2)
	Sub-adult	M	2.0	0−2	0.2±0.6 (280.3)	4.8	0−2	0.4±0.8 (183.6)	–	–	–	2.2	0−2	0.2±0.6 (275.0)
		F	3.3	0−2	0.3±0.6 (185.2)	3.2	0−1	0.3±0.5 (170.8)	7.7	0−2	0.6 ±0.7 (118.4)	4.3	0−2	0.4±0.6 (155.0)
	Juvenile		21.1	0−13	2.1±3.3 (154.3)	3.2	0−1	0.3±0.5 (170.8)	20.0	1−3	1.6±0.7 (45.5)	16.8	0−13	1.6±2.5 (156.1)
	Infant		17.1	0−4	1.7±1.4 (80.0)	29.0	0−6	2.6±2.0 (77.3)	12.3	0−2	1.0±0.5 (53.0)	18.6	0−6	1.7±1.5 (84.4)
% Adults in the population			56.9			60.9			61.2			58.8		
% Non-adults† in the population			43.1			39.1			38.8			41.2		

†Non-adults = sub-adults + juveniles + infants

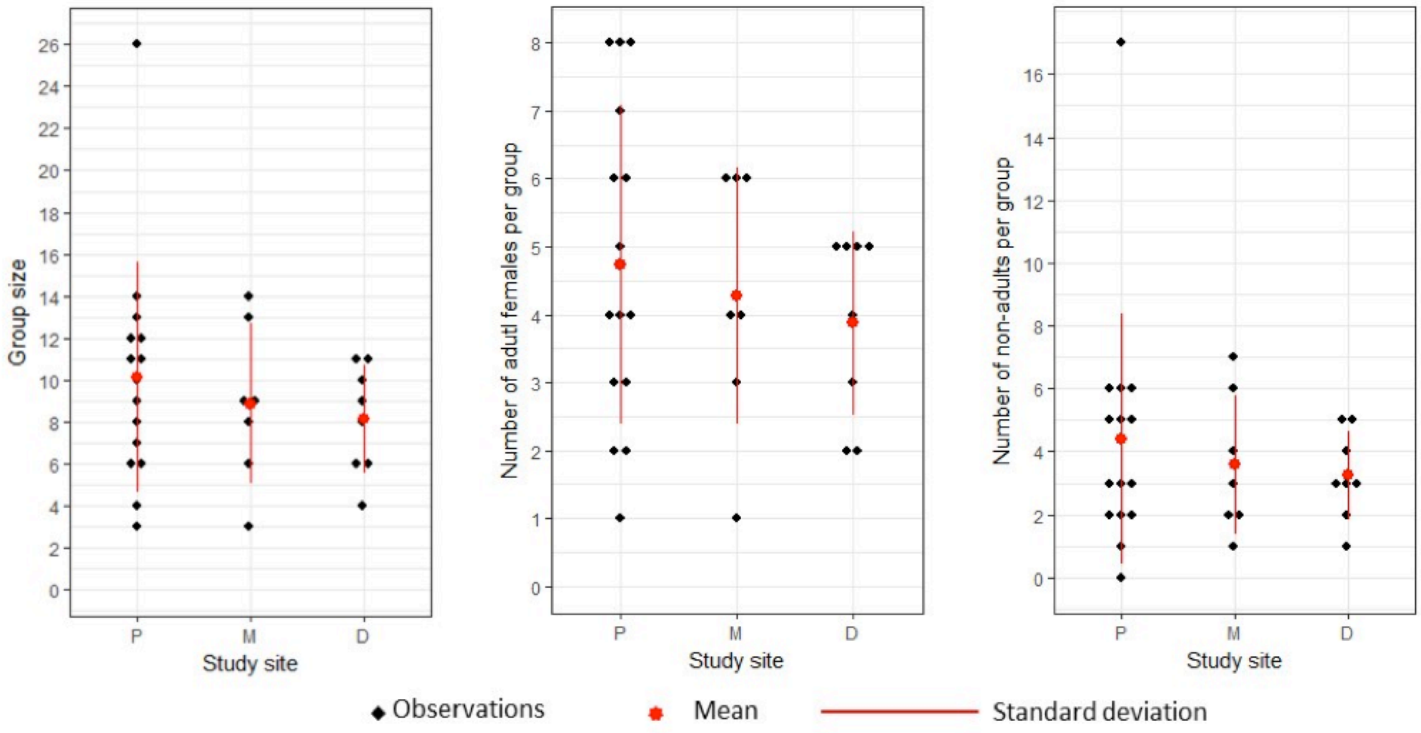

Figure 3. Group sizes of langur groups counted in each study site (P − Pannipitiya, M − Malabe, D − Dombagaskanda Forest Reserve)

(adult females and non-adults per group) at each study site. Coefficient of variation (CV) was calculated to compare the dispersion of group size and composition (adult females and non-adults per group) relative to the means. Density (individuals/ha) was calculated by dividing the number of individuals counted at each study site by the total area surveyed in each site. It is assumed that all langurs within the survey areas were counted in this study.

Results

In all, 284 western purple-faced langurs in 30 groups and five solitary males were counted in the three study areas (Table 1). All groups had a single adult male. Sub-adult males were observed in four of 22 non-forest groups and none were found in forest groups. The adult sex ratio in uni-male groups was 1:4.4. There were four groups (group sizes 3, 4, 8 and 11) in non-forest areas that were not seen to have any infant or juvenile size classes, but did have pregnant females or females showing adult female characteristics, indicating that they were reproductive units.

There was no detectable difference in the three study sites in terms of group size (Kruskal-Wallis, $H = 0.84$, $df = 2$, $p = 0.66$), number of adult females per group (Kruskal-Wallis, $H = 0.72$, $df = 2$, $p = 0.70$), and the number of non-adults per group (Kruskal-Wallis, $H = 0.26$, $df = 2$, $p = 0.88$). The Coefficient of Variation (CV) for group size and counts obtained for age/sex categories, however, was greater in the non-forest study sites compared to the forest study sites (Table 1). There was also a difference in the CV between the two non-forest sites. Forest groups had no more than 11 individuals, while nearly one-third of the non-forest groups had twelve or more individuals (Fig. 3). The seven non-forest groups with 12 or more individuals contained 5 to 8 adult females. Densities of langurs in non-forest areas were lower than in forest areas (Table 1).

Discussion

Our study populations consisted of solitary males and bisexual groups containing a single adult male. There were no predominantly male groups (PMGs) identified during this study. However, Dela (1998) and our recent studies (unpubl. data) recorded such groups of *S. v. nestor* in other areas. The lack of observations of PMGs may therefore be a limitation of the small survey area of this study. The adult sex ratio in harem groups observed in this study (1:4.4) is consistent with the male to female sex ratios in harem groups recorded by Rudran (1970) for the northern purple-faced langur *S. v. philbricki* (1:4.1), but higher than the ratio recorded for the highland purple-faced langur *S. v. monticola* (1:3.3) and also for *S. v. nestor* (1: 3.5) by Moore *et al.* (2010).

The mean group sizes in all sites we studied are within the range of mean group sizes recorded in other extensive studies done on *S. v. nestor* (mean=11.1; range 4−21; n =13 [Dela, 1998], mean = 9.3; range 4−19; n = 21 [Parker *et al.* 2008]) and studies of *S. v. monticola* (mean = 8.9, range 3−14, n = 27) and *S. v. philbricki* (mean= 8.4, range 3−15, n = 33) by Rudran (1970). The lack of detectable differences between the group sizes, number of adult females per group, and non-adults per group of forest and non-forest populations indicates that habitat loss and fragmentation in non-forest habitats have not had an effect on the average group size and composition (Parker *et al*. 2008). There was, however, higher variability in group sizes and composition in non-forest groups than in forest groups. There was also a detectable difference in variability in group size and composition even between the two non-forest study sites. This high variability observed in non-forest study sites could be due to the greater spatial variability in habitat quality of the home range occupied by each group (Marshall 2010).

We recorded one of the largest groups (26 individuals) observed to date for this species. Maximum group size recorded in the scientific literature for purple-faced langurs is 21 (Dela 1998). This large group observed in our study consisted of one adult male, eight adult females, an exceptionally large number of juveniles (13) and four infants. Large groups, at the upper end of the range of sizes (n >15) have been recorded in several previous studies conducted in non-forest habitats (Dela 1998; Parker *et al.* 2008; Moore *et al.* 2010). Such large groups may be aggregations of members from several groups that have lost their territories due to habitat destruction, as has been suggested for *S. v. nestor* (Moore *et al.* 2010), and for other primates in similar situations (Bishop *et al.* 1981; Marshall *et al*. 2005).

These large groups observed may also have resulted from male turnover (Rudran 1973). All our groups contained only one adult male; the large groups resulted from a large number of adult females. The occurrence of a single adult male and many females can be explained by the behavior of adults of both sexes during male turnover or invasions (Rudran 1973). During these social changes there is intense aggression between the resident and the invading male(s). This results in the resident male being evicted from the group along with his immature offspring of both sexes, and one of the invaders then replacing him. Hence only a single adult male remains in the invaded group after the social change. On the other hand, resident females appear to tolerate females that have reached adulthood in PMGs and enter their group with the invader male (Rudran 1973). After several social changes, therefore, there still remains a single adult male, but a gradually increasing number of adult females.

These large groups that may be formed by fusion of the incoming females during adult male replacements may be permanent in contrast to an aggregation of groups that have lost their habitats, which may be a foraging group of more temporary nature. It would, therefore, be valuable to census these large groups periodically to determine if the numbers are maintained continually. In fragmented landscapes of poor habitat quality and low resource availability, large groups may have to travel longer distances and cover larger areas in order to find food to fulfil their energy requirements resulting

in each individual spending more energy compared to being in a smaller group (Eisenberg *et al*. 1972; Wrangham *et al*. 1993). Therefore it would be important to study the resource use of these large groups, to understand how they survive in their non-forest habitats which are fragmented and constantly subjected to change.

The densities recorded for our study populations are close to those recorded by Rudran (1970) for *S. v. philbricki* at Polonnaruwa (2 ha^{-1}) and *S. v. monticola* of Horton plains (1 ha^{-1}). High densities in fragmented and isolated landscapes have been observed in previous studies due to "crowding" (Banks *et al.* 2007; Arroyo-Rodríguez and Dias 2010), but these numbers tend to decrease in the long term (Debinski and Holt 2000). Lower density recorded in non-forest study sites of our study may therefore be a long-term effect of habitat fragmentation.

Our study shows that a considerable population inhabits even small areas of fragmented human modified habitats. In non-forest study sites, however, there are areas such as paddy fields, play grounds and other open habitats that cannot be occupied by these arboreal langurs due to lack of canopy connections, restricting movements and access to resources (Dela 2011). As distance between suitable habitats increases and habitat size decreases, these populations will become further isolated (Arroyo-Rodriguez and Dias 2010), inevitably leading to local extinctions (Parker *et al.* 2008).

In our study, we recorded that adults outnumbered immature individuals in both forest and non-forest populations. Similar proportions were recorded for *S. v. philbricki* and *S. v. monticola* in Rudran (1970). However, the *S. v. philbricki* population showed a decline in population over 10 years (Rudran 2013). A systematic study should be carried out, therefore, to understand factors such as birth rate, age-specific mortality and recruitment of immature individuals into adult age classes, to determine if disparity in numbers of adults and non-adults in the population may also pose a threat for their long-term survival in fragmented habitats.

The results of this study provide opportunities to identify future research areas that would promote the conservation of *S. v. nestor*. It is very clear that the area of occurrence and area of occupancy are very different due to large areas of unsuitable habitat in non-forest areas. A more systematic investigation of density and distribution with a better assessment of habitat quality of the areas these langurs occupy is therefore recommended. The survival ability of large groups and group dynamics in non-forest areas will also require further investigation. An extensive study at landscape level in this heterogeneous landscape is essential for designing conservation plans for this Critically Endangered langur to ensure its future survival.

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Authors' addresses:

Surendranie J. Cabral, Department of Zoology and Environment Sciences, University of Colombo, Colombo, and Foundation for Nature Conservation and Preservation, Panadura, Sri Lanka, **Amila P. Sumanapala**, Foundation for Nature Conservation and Preservation, Panadura, Sri Lanka, **Devaka K. Weerakoon** and **Sarath W. Kotagama**, Department of Zoology and Environment Sciences, University of Colombo, Colombo, Sri Lanka, and **Rasanayagam Rudran**, Smithsonian Conservation Biology Institute, Washington DC, USA.

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