

**Group size and composition in the common langur  
(*Semnopithecus entellus*): A study on the influence of  
resource abundance and distribution using ground  
based methods and remote sensing**

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By

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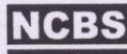
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### Declaration

I declare that the thesis entitled "Group size and composition in the common langur (*Semnopithecus entellus*): A study on the influence of resource abundance and distribution using ground based methods and remote sensing" comprises research work done by me under the guidance of Dr. Ajith Kumar and co-guidance of Dr. Anindya Sinha. The work is original and has not been done earlier by anyone else. Part of this work, which is related to or similar to work done by other researchers, has been referred to in this thesis at appropriate places. The results presented in this thesis have not been submitted previously to this or any other University for an M.Sc. or any other degree.

Signature of the Guide  
(Dr. Ajith Kumar)

Signature of the Candidate  
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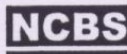
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### Certificate

I declare that this thesis entitled "Group size and composition in the common langur (*Semnopithecus entellus*): A study on the influence of resource abundance and distribution using ground based methods and remote sensing" comprises research work carried out by Divya Vasudev at the Centre for Wildlife Studies under my guidance and the co-guidance of Dr. Anindya Sinha during the period 2005-2006 for the Degree of Master of Science in Wildlife Biology & Conservation of the Manipal Academy of Higher Education (MAHE). The results presented in this thesis have not been submitted previously to this or any other University for M.Sc. or any other degree.

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## SUMMARY

The objective of the study was to assess the influence of resource abundance and distribution on group size and composition in the common langur (*Semnopithecus entellus*). This tests the folivore paradox of feeding competition, which arose from assumptions that the leaves that made up the major portion of the folivore diet were inexhaustible. The study species provides immense opportunities for this, showing wide variations in group size and composition. In addition, the applicability of NDVI to primate ecological studies was tested, using this question as an example. Data was collected between January and May, 2006, from parts of Nagarahole National Park, Mudumalai Wildlife Sanctuary and Bandipur Tiger Reserve. NDVI was extracted from satellite imagery taken by Indian Remote Sensing satellite, IRS-P6 (LISS-III sensor), on the 27<sup>th</sup> of February, 2006, which coincided with the period of ground-based data collection.

Groups were opportunistically located, and followed to obtain data on group size and composition. Group size and composition of 94 groups were obtained, and 35 all-male groups were located. The bisexual groups varied in size from 7 to 40, with adult male group size varying from 1 to 8 and adult female group size, from 2 to 20. Vegetation was sampled from 17 grids of dimensions, 1 km × 1 km, each with 12 plots of dimensions, 25 m × 25 m. Species encountered in plots were categorized as food and non-food species based on a compilation from available data, and supplemented by observations made during the period of this study. Basal area of food species per plot was aggregated for each grid. Mean basal area of food trees gave an index of resource abundance, and as a coefficient of variation of basal area of food trees, gave an index of resource distribution.

Group size and composition of the common langur was found to increase with an increasing degree of clumping of resources. Increase in resource abundance coincided with decreased group size, probably an artifact of the effect of distribution of resources, which in itself was negatively correlated with resource abundance. The effect of resources on adult males was stronger than on adult females. There was no evidence of reaction of group size to predation presence or risk of take-over.

NDVI, though reported as a good indicator of above-ground canopy cover, showed, contrarily, a negative relationship with the ground-based index of resource abundance. The reason for this is probably the presence of *Lantana camara* in high densities in parts of the study area. Group size showed a weak positive relationship with NDVI. Within Mudumalai Wildlife Sanctuary, however, group size reacted negatively to NDVI, as expected from its relationship with resource abundance. Confounding factors, such as scale and under-storey can mask, or even completely change the relationship between NDVI and resource abundance of langurs. The use of NDVI, though extremely advantageous, should be treated with caution, and any interpretation must follow an understanding of all or most of the factors that do contribute to NDVI.

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## INTRODUCTION

Group size and composition are an extremely important aspect of sociobiology. Primate groups are of different types, ranging from monogamous primates, such as the saki, to large fission-fusion groups, such as those formed by chimpanzees. Primates benefit from group-living when this makes resource acquisition easier, or when it is beneficial in dealing with predators (Terborgh & Janson 1986). These two factors also determine the size of primate groups. Predation risk tends to increase the size of primate groups, so they benefit from increased vigilance (van Schaik & Horstmann 1994). Resources, as they increase in abundance, relax limits on the size of groups formed, thus, allowing for larger groups (Chapman & Chapman 2000). Resource distribution determines the formation of resource patches that can accommodate groups of primates within them (Johnson *et al.* 2002). In addition, social factors also influence group size (Chapman & Pavelka 2005). Intra-group aggression can limit the size of groups formed, while inter-group competition would increase the size.

Folivores have been of special interest as consensus on the existence of feeding competition among these primates has not yet been reached (Snaith and Chapman 2005). This confusion arises due to the common supposition that leaves, which form the major component of the folivore diet are inexhaustible (Garber 1987) while fruits, which form a major component of the frugivore diet, are. This is contrary to evidence, however, of clumping of folivore resources, and of the existence of feeding competition among them (Koenig *et al.* 1998).

The common langur shows great variation in group size (Koenig & Borries 2001). Ideally, a study of resource influence on group size would have to span the entire range of habitats of the primate. This is not possible due to difficulties associated with collection of data on vegetation attributes.

One way of addressing this is to use previous data as a meta-analysis. Data on group size being widely available for the common langur, this has been done before (Treves and Chapman 1996). The results of this study indicate that social factors determine group size rather than predator presence or resource abundance.

Another method to obtain information over a short period of time, and a large scale is through remote sensing (Pettorelli *et al.* 2005). Simple spectral indices, such as normalised differential vegetation index (NDVI), which are ecologically meaningful, have scope for use in such studies and have been demonstrated to be extremely useful in past studies (Pettorelli *et al.* 2005).

In this study, I examine the influence of resource distribution and abundance on group size and composition of langurs. At a larger scale, I also examine the effects of predator presence, and the presence of all-male groups. In an attempt to enable research on a larger scale, I also test the applicability of NDVI, to langur ecological studies. NDVI was chosen since it has been shown to have high correlation with vegetation and biomass.

I conducted this study in the large and contiguous forests in Nagarahole National Park, Bandipur Tiger Reserve, and Mudumalai Wildlife Sanctuary, between January

and May, 2006. During this time, data was collected on group size and composition by opportunistically locating groups and following them. Resource abundance and distribution was quantified per plot as the basal area of food trees. NDVI was extracted from satellite imagery of February, 2006.

The first chapter of the thesis deals with the question of resources and their influence on group size and composition. At a larger scale, presence of predators and all-male bands are also examined. This is presented in the form of a manuscript, following the format of the journal *Behavioral Ecology and Sociobiology*.

Chapter 2 looks at NDVI, and its applicability to ecological studies. There are two objectives of this chapter. One is to test whether NDVI can be used as a surrogate for resource availability and distribution. The other objective is to examine whether NDVI shares a relationship with group attributes. This is also presented in the form of a manuscript, following the format of the journal *American Journal of Primatology*. Since there are certain sections relevant to both manuscripts, these have been repeated.

In the concluding section, I synthesise the results of the above two chapters.

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**Langurs of Mudumalai Wildlife Sanctuary (top), Bandipur Tiger Reserve (center), and Nagarhole National Park (bottom)**

**CHAPTER I: Effect of abundance and distribution of resources on group size and composition in, the common langur (*Semnopithecus entellus*)**

**Abstract**

It has been of great interest to test whether grouping in folivores is governed by resources, or other factors, such as predation or social effects. Resources can affect grouping through variation in abundance and distribution. This was tested on a folivorous primate, the common langur (*Semnopithecus entellus*), in a contiguous patch of forest in Bandipur Tiger Reserve, Mudumalai Wildlife Sanctuary and Nagarahole National Park, which together cover an area of nearly 1850 km<sup>2</sup>. The size and composition of 94 bisexual groups, varying in size between 7 and 40 were obtained. Vegetation was sampled from seventeen grids of dimension 1 km × 1 km, each containing twelve 25 m × 25 m plots. Basal area of food trees per plot was aggregated at the level of the grid to its mean and coefficient of variation, which represented resource abundance and distribution, respectively. Adult male and adult female group sizes were analyzed separately, to test for differential effects on age-sex categories. Group size increased as resources became spatially more heterogeneous. Contrary to predictions of the ecological-constraints model, abundance of resources had a negative effect on group size. Since resource abundance and distribution were negatively correlated, this is probably an artifact of the effect of distribution on grouping. Within this environmental constraint, langurs may react to other factors. This study did not find any evidence supporting the direct effects of predator presence, or of risk of take-over. Contrary to what is expected, adult males reacted more strongly, and predictably to resources than adult females.

## **Introduction**

Three main factors are said to determine group size and composition of primates; resources, predation and conspecific threat (Treves and Chapman 1996). The relative strength of each of these factors has been of great interest to primatologists, and seems to differ depending on the species in question, and on ecological factors acting on the species.

Resources have been a subject of much study in recent years. Two aspects of resources affect group size; abundance and distribution. Resource abundance is the predominant factor acting on group size in species where feeding competition is a limiting factor. This forms the basis of the ecological constraints model, which predicts an increase in day travel in larger groups, due to the increased nutritional requirements (Gillespie and Chapman 2001). It has, subsequently, been found that day travel and group size do not act in isolation. Instead, there is interplay among group size, day travel, and resource abundance (Gillespie and Chapman 2001).

Though this model applies to most frugivores, there has been some confusion in the results obtained from studies on folivores (Steenbeck and van Schaik 2001; Struhsaker et al. 2004). This is due to the fact that leaves, which form the primary component of the folivore diet is less exhaustible than fruits, the primary component of the frugivore diet (Garber 1987). However, there has been some evidence of feeding competition (Snaith and Chapman 2005) and of resources having an effect on group sizes in folivores as well (Chapman and Chapman 2000), which implies the exhaustible nature of their resources.

This comes about due to the distribution of the food resources of folivores (Eisenberg et al. 1972). Clumped distribution enables the formation of large groups, since this leads to the formation of resource patches that can accommodate a large

number of individuals (Johnson et al. 2002; Terborgh and Janson 1986). The interpatch distance being large, dispersal is discouraged (Post 1984).

Predation pressure has the effect of increasing the number of members in the group, for increased vigilance and defense (van Schaik et al. 1983). In areas of high predation risk, large groups have the selective advantage of early detection of predators (van Schaik et al. 1983).

Social factors are more complex. Larger groups may exhibit more male-male, or even female-female competition and thus be selected against (Chapman and Pavelka 2005). Groups can also be affected by the risk of infanticide. Infanticide has been reported following take-over in a number of primates (Hrdy 1979; Sterck 1998). This can have a multitude of effects. In some species where larger groups experience more take-over, smaller groups may be selected for (Steenbeck and van Schaik 2001). What has been a more widespread observation is that larger groups, especially multi-male groups, experience lower risk of infanticide (van Schaik 2000). This is simply due to outsider males being more hesitant to attempt take-over of a group with more defenders (van Schaik 2000). Large groups have, in fact, been documented to have higher infant survival rates (Steenbeck and van Schaik 2001), in addition to higher natality (Struhsaker et al. 2004). This may arise from protection against infanticide, predation or more efficient acquisition of resources. The risk of infanticide should thus push the group size upwards.

The cost of infanticide may also vary between areas of equal infanticide risk. Resource abundance has physiological effects on reproductive efficiency of females, affecting the mean age of first parturition, length of lactation time, gestation period and inter-birth interval (Borries et al. 2001). In low nutritional areas, with longer inter-birth intervals, it is of great advantage to have larger groups, since the cost of

infanticide is higher. This would especially be true if resources are clumped, and thus defendable, in low nutritional areas.

The optimal group size of any species occupying a particular habitat, therefore, would be determined by these factors acting in tandem. For different species, depending on their ecology and sociobiology, different factors are of significance. Often, the effect of some factors vary with age-sex category. For example, resources are often said to have a stronger effect on the adult female group size (Gehrt and Fritzell 1998), and predation acts on the number of adult males in a group (van Schaik and Horstermann 1994).

This study intends to examine the effect of resources on the group size of an Asian colobine, the common langur, *Semnopithecus entellus*. Though the effect of resources on primates has been much studied, a large number have made comparisons across taxa, adding an additional confounding factor in the relationship, in terms of phylogeny (Sterck and van Hooff 2000). The common langur, in this sense, forms an ideal species for studying this issue. It is distributed through the Indian sub-continent, occurring in a variety of habitats ranging from semi-deserts to moist deciduous forests, evergreen forests to alpine habitats, up to about 4000 m above msl in altitude (Koenig and Borries 2001). It shows tremendous variation in group sizes, with average group sizes ranging from 11 to 64. Amongst these, uni-male, age-graded male, as well as multi-male groups are encountered (Koenig and Borries 2001).

I examine the relationship of total, adult female and adult male group size with resource abundance and distribution. If resources are a limiting factor, group sizes should increase with increasing resources, as predicted by the ecological constraints model.

Karanth and Sunquist (1995) have reported predation of langurs by three large predators; tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) in Nagarahole National Park. In this situation, langur groups would be at the maximum possible size for the ecological conditions of the area in question. Since the scope of this study does not allow for the estimation of daily travel in different areas, it could be assumed that since the groups are already at the maximum that the habitat allows, their daily travel is maximum as well (Korstjens and Dunbar in press). This would imply a strong relation between group size and resource abundance, as per the ecological-constraints model.

Independent of this, distribution of resources is also hypothesized to have an effect on grouping. This hypothesis predicts an increase in group size with clumping of food resources. Resources may have different effects on males and females within a group, as might predation risk, or social factors. For this reason, adult male group size and adult female group size will be dealt with separately in analysis, in addition to total group size. The influence of the presence of predators and all-male bands are also examined, but on a larger scale.

## **Methods**

### **Study area**

Data on group composition and vegetation were collected from parts of Bandipur Tiger Reserve (TR), Nagarahole National Park (NP) and Mudumalai Wildlife Sanctuary (WLS) between January and May, 2006 (Fig 1). These protected areas form a contiguous stretch of forest, exhibiting a variety of habitat conditions. The sub-species inhabiting this area is of some doubt.

Bandipur TR (11°35'34" to 11°55'02" N and 76°12'17" to 76°51'32" E), spanning 880 km<sup>2</sup>, is at the foothills of the Western Ghats and has undulating hills, its

altitude ranging from 780 m to 1454.5 m above msl. The mean annual rainfall is 914 mm in Bandipura range. It contains scrub forests, southern tropical dry deciduous, and southern tropical moist deciduous forests, with major tree species *Tectona grandis*, *Anogeisus latifolia*, *Terminalia alata*, *Butea monosperma*, and *Lagerstroemia lanceolata*. Herbivores, such as gaur (*Bos gaurus*), chital (*Axis axis*), sambar (*Cervus unicolor*), and elephants (*Elephas maximus*), and carnivores, tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) are found to inhabit this area. The other primate species found here is the bonnet macaque (*Macaca radiata*) (Anon. 2001).

Nagarahole NP (11°50' to 12°15' N and 76°0' to 76°15' E), spanning 644 km<sup>2</sup>, receives mean annual rainfall of 1500 mm in the west to 900 mm in the east. The park consists of three major vegetation types, dry deciduous forests, moist deciduous forests, and teak-dominated forests (Karanth and Sunkist 1995). It shares its major flora and fauna with Bandipur TR.

Mudumalai WLS (11°31' to 11°39' N and 76°27' to 76°43'E), spanning 321 km<sup>2</sup>, lies between 850 m and 1250 m above msl. The mean annual rainfall it receives is 800 mm to 1800 mm. It contains tropical dry-thorn, dry-deciduous, moist deciduous and semi-evergreen forests (Vidya et al. 2003). The major floral and faunal species are shared with the Bandipur TR, with which it shares its northern boundary (Fig 1).

## **Field Methods**

### **Group Composition**

The study area had an elaborate network of roads, which facilitated location of groups. Once located, each group was followed for the time necessary to obtain reliable counts. The langurs were classified into age-sex categories (Table 1).

Locations of all groups were marked on a Garmin 72XL Geographic Positioning System.

The time spent with a group ranged from 15 minutes to 2 hours. If after a certain period of time, it did not seem possible to obtain reasonable counts, all visible members were counted and classified. This was only used to obtain the percentage of all-male groups in each area. The group attributes used for analysis included total group size, adult male group size, and adult female group size.

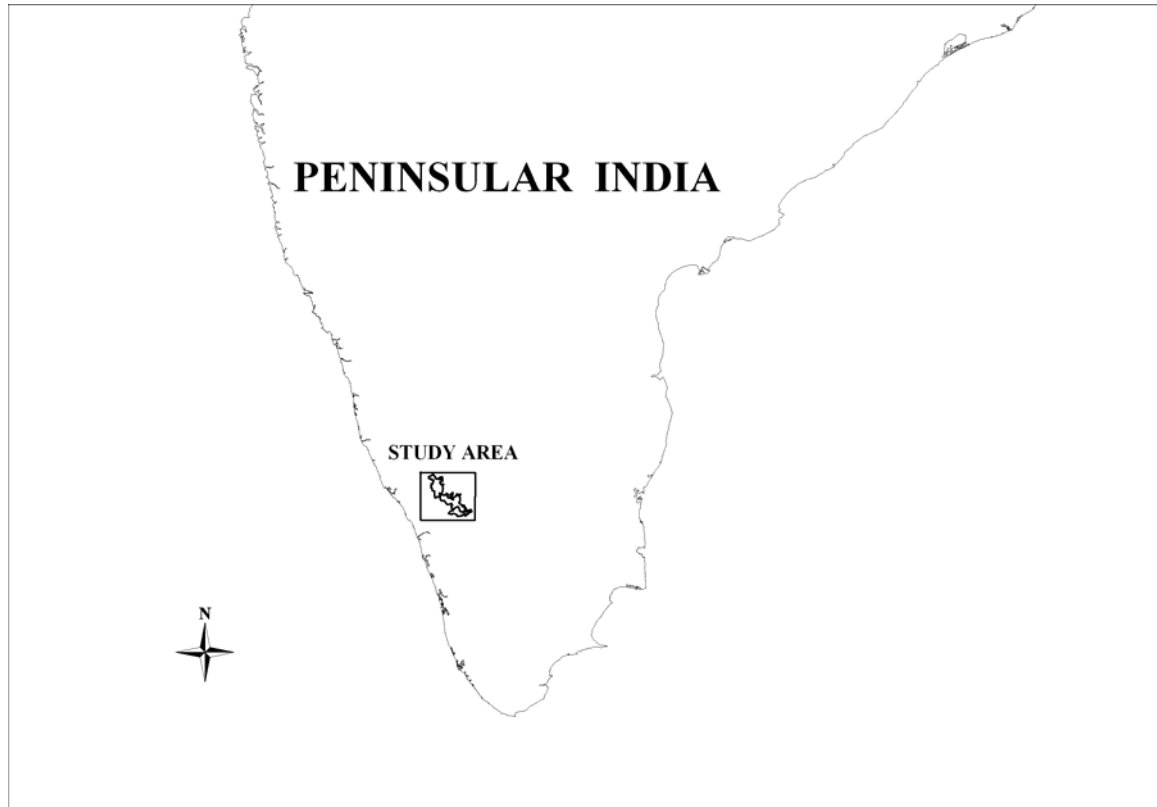
**Table 1.** Classification of group members

<b>Category</b>	<b>Description</b>
Adult male	Sexually and socially mature males, with well developed secondary sexual characteristics
Adult females	Sexually and socially mature females, with well-developed secondary sexual characteristics
Sub-adults	Members of the group that are sexually, but not socially mature. As far as possible, sub-adults were classified into males and females.
Juveniles	Sexually immature weaned members of the group,
Infant Stage 2	Infants with white pelage.
Infant Stage 2	Infants with black pelage. These members are mostly found with an adult female.

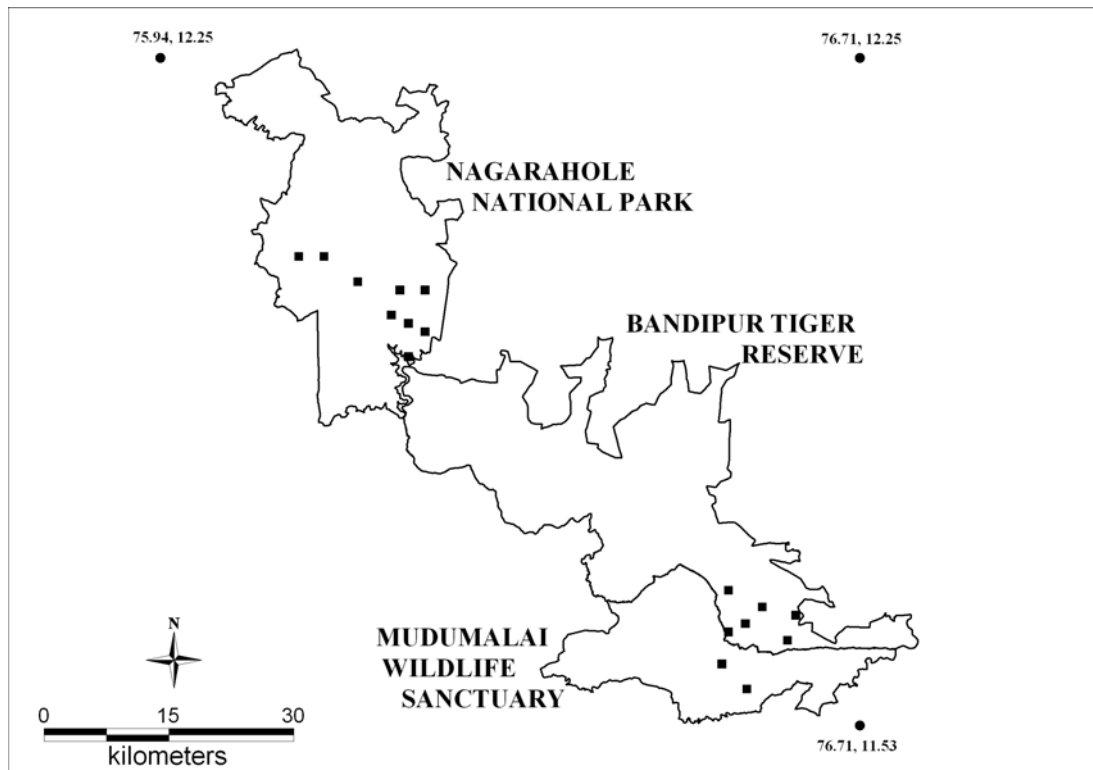
#### *Vegetation*

A previously laid grid layer of dimensions 1km × 1km (ATREE, unpublished data) was used for Nagarhole NP and Bandipur TR. For Mudumalai WLS, a grid layer of the same dimensions was laid, using the software MapInfo 7.5 SCP (MapInfo Corporation 2003).

Seventeen grids spread over the study area were chosen from this layer, based on the location of groups (Fig 1). The abundance and distribution of food trees were sampled from these 17 grids.



STUDY AREA



**Fig 1.** Locations of the seventeen 1km × 1km vegetation grids

Within each chosen grid, twelve 25 m × 25 m plots were randomly chosen. The locations of these were obtained from MapInfo 7.5 SCP (MapInfo Corporation 2003), and these were then located on ground using a GPS. Within each plot, all trees with GBH (girth at breast height)  $\geq 30$ cm were enumerated and identified. The GBH of each was noted. Canopy cover was estimated for each plot using a canopy densiometer. Total basal area was calculated for each plot.

A list of food tree species of the common langur, compiled from previous studies in different areas (Hrdy 1977; Hladik 1977; Koenig et al. 1998; Palaniappan 1987; Ripley 1970; Tewari 1991) and *ad libitum* feeding observations made during this study was used to identify food species of the common langur. The subset of food species in each plot was used for analysis.

For each of the 17 grids, the mean and coefficient of variation of the basal area of food trees per plot were calculated. Mean basal area of the food trees was taken as

an index of resource abundance. Measures derived from the diameter at breast height have been found to accurately predict leaf biomass (Chapman and Pavelka 2005).

The co-efficient of variation among plots that fell within each grid gives an index of heterogeneity within that grid. This measure of heterogeneity is used as an index of clumping. Since this is taken collectively for all food resources, it is an index of clumping of food resources as a whole, and not of individual species.

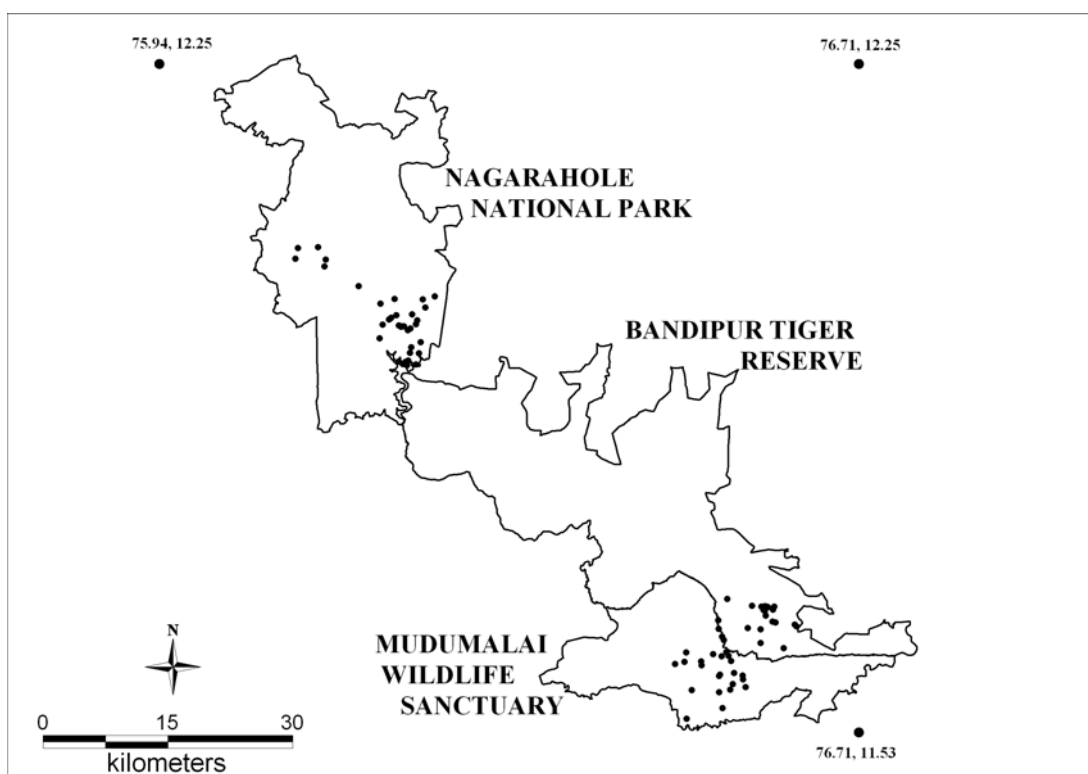
### **Analytical Methods**

Regressions were used to examine the relationships of group attributes with resource abundance and distribution, represented by mean and coefficient of variation of basal area, respectively. Since groups were located opportunistically, without consideration of the grid network, the number of groups per grid varied between 1 and 8, with nine grids having more than a single group. In order to avoid repeated measures, a single group was randomly sampled from each grid, and a regression was performed on these sampled groups. This was repeated 500 times, generating a series of regression parameters, and the results presented are those aggregated over these iterations (Oommen and Shanker 2005). The median  $p$  and fraction of significant regressions out of 500 were used to decide the significance of relationships, and the median slope and median  $R^2$  were used to compare relationship strength. All analysis was carried out using SPSS 11.5 (SPSS 2002) and SPLUS 6.1 (Insightful Corp. 2002).

## Results

### Group Size and Composition

In total, 232 groups were located, out of which reliable counts and compositional data were obtained for 94 bisexual groups (Fig 2). These varied in size between 7 and 40 with a mean of 18.61 ( $\pm 7.1$ , S.E. of mean) and a median of 18.5. (Fig 3a). The number of adult males in a group varied between 1 and 8 (mean=2.59 $\pm$ .15) (Fig 3c), and the adult females between 1 and 20 (mean=8.59 $\pm$ .35) (Fig 3e). Adult females accounted for maximum variation in group size ( $R^2=.547$ ). Of the 232 groups, 35 were all-male groups. The size of all-male groups ranged from 6 to 16, with a mean of 7.78 ( $\pm$ .563), and a median of 7. The ratio of all-male groups to bisexual groups was .058 in Mudumalai WLS, .167 in Bandipur TR, .423 in Nagarahole NP.



**Fig 2.** Locations of the 94 groups for which reliable counts were obtained

Out of 94 groups, 45 were located within the 17 grids of 1 km  $\times$  1 km, from which the vegetation was sampled, or adjacent to them. These groups formed a

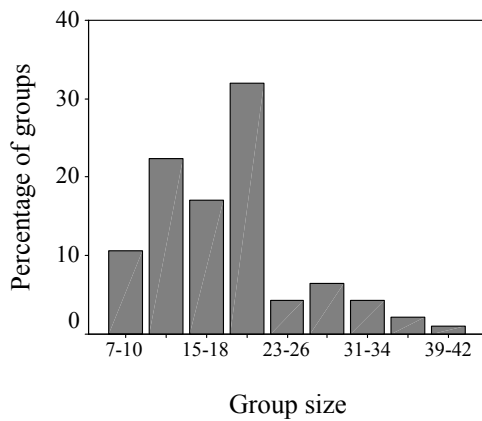
random sample of all the groups located (mean=18.87±1.13) (Fig 3b, 3e, 3f). The number of groups within a grid varied from 1 to 8, with 8 of the 17 grids having only one group.

### Vegetation

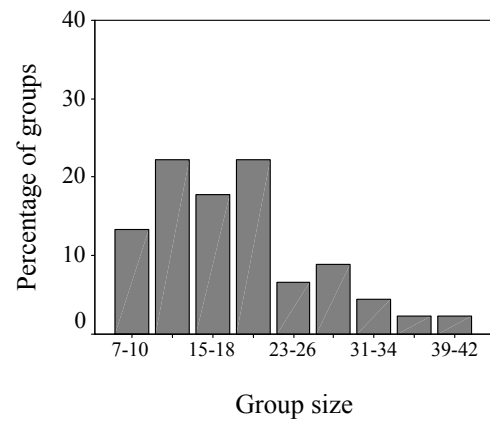
Number of trees per plot varied between 0 and 44 (mean=13.58±.56, median=12.5).

Between 0 and 13 species (mean=5.24±.17, median=5) were encountered in each plot.

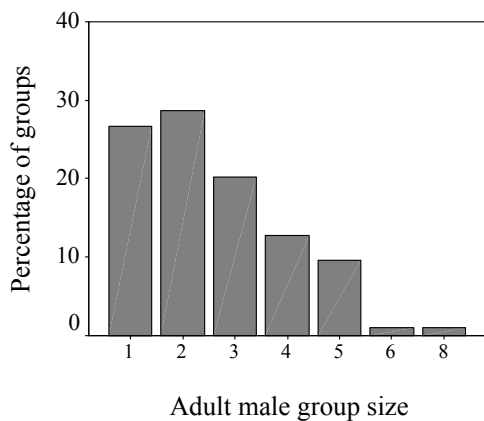
Basal area varied from 0 to 32749.66 cm<sup>2</sup> (mean=10501.02±456.38 cm<sup>2</sup>, median=9652.88 cm<sup>2</sup>).



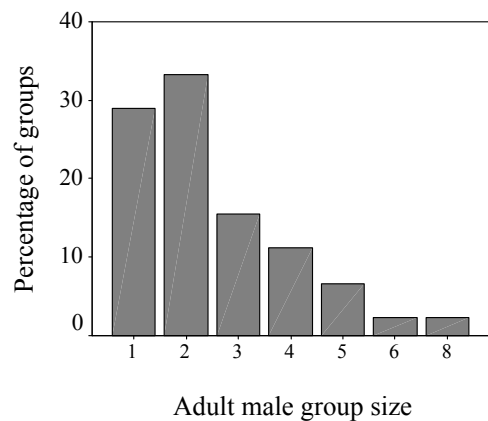
(a)



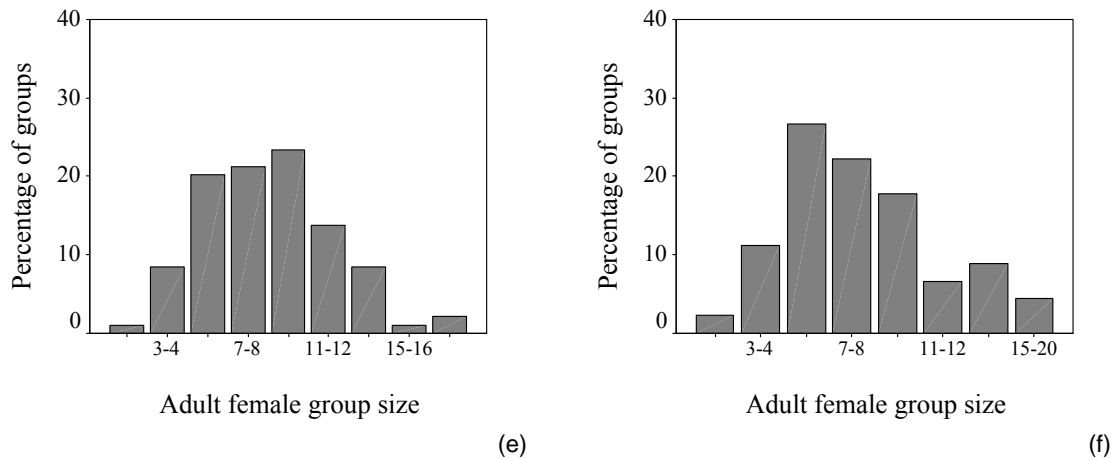
(b)



(c)



(e)



**Fig 3.** Frequency distribution of total, adult male and adult female group sizes for (a), (c), (e) all 94 groups and (b), (d), (f) 45 sub-sampled groups, respectively

Out of 68 tree species encountered, 22 species have been reported as food species of the common langur from studies elsewhere. An additional six species (*Acacia concinna*, *Dalbergia latifolia*, *Garuga pinnata*, *Pterocarpus marsupium*, *Radermachera xylocarpa* and *Terminalia alata*) were recorded as food species based on observations made during the present study. A list of food species encountered in plots is given in Table 2.

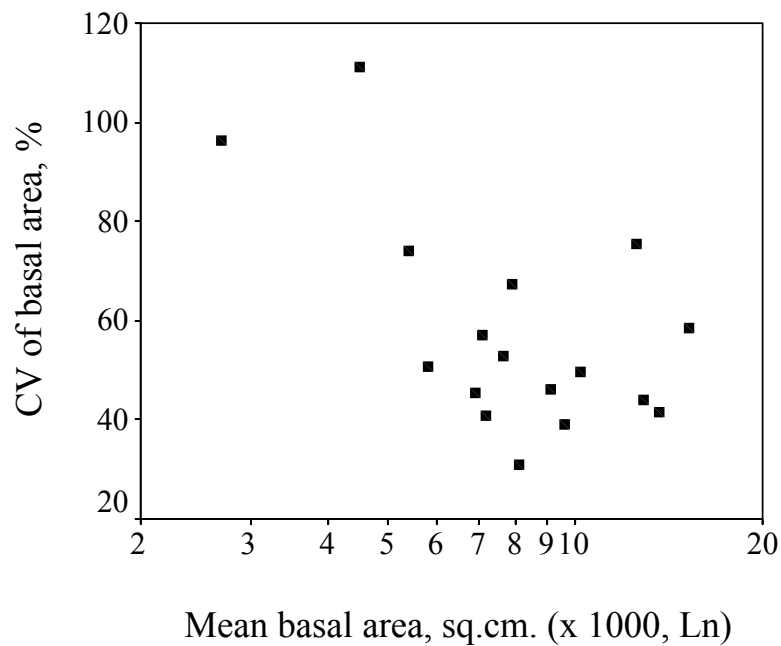
**Table 2.** Food species encountered in vegetation plots

<i>Ficus benghalensis</i> <sup>a,b,c,d</sup>	<i>Cassia fistula</i> <sup>a,b</sup>
<i>Ficus religiosa</i> <sup>a,b,c,d</sup>	<i>Mallotus philippensis</i> <sup>d</sup>
<i>Bauhinia racemosa</i> <sup>a,c</sup>	<i>Randia dumetorum</i> <sup>a</sup>
<i>Dalbergia latifolia</i>	<i>Terminalia alata</i>
<i>Albizia lebbek</i> <sup>c,d</sup>	<i>Terminalia bellirica</i> <sup>c,d,e</sup>
<i>Bombax ceiba</i> <sup>d</sup>	<i>Mangifera indica</i> <sup>a,c</sup>
<i>Lagerstroemia parviflora</i> <sup>d</sup>	<i>Butea monosperma</i> <sup>a,d</sup>
<i>Ziziphus xylopyrus</i> <sup>d</sup>	<i>Emblica officinalis</i> <sup>d</sup>
<i>Ziziphus oenoplia</i> <sup>a</sup>	<i>Syzygium cumini</i> <sup>a,b,d</sup>
<i>Premna tomentosa</i> <sup>a</sup>	<i>Radermachera xylocarpa</i>
<i>Garuga pinnata</i>	<i>Schleichera oleosa</i> <sup>a,b</sup>
<i>Bridelia retusa</i> <sup>a,b</sup>	<i>Acacia concinna</i>
<i>Diospyros montana</i> <sup>a</sup>	<i>Anogeissus latifolia</i> <sup>d</sup>
<i>Adina cordifolia</i> <sup>a,b</sup>	<i>Pterocarpus marsupium</i>

Sources : (a) Ripley 1970(b) Hladik 1977(c) Hrdy 1977(d) Tewari 1991(e) Koenig et al. 1998. 6 species were identified as food species based on observations made during the course of this study.

The number of food trees in a plot varied from 0 to 43 (mean=10.83±.53, median=10), and the number of food species from 0 to 8 (mean=3.72±.12, median=4). Basal area of food trees ranged between 0 and 31585.03 cm<sup>2</sup> (mean=8612.58±410.85 cm<sup>2</sup>, median=7849.41 cm<sup>2</sup>).

Food trees formed between 0 and 100% of all trees within plots. In 75% of the plots, food trees comprised more than 65% of all trees, and food species comprised more than 60% of all species. 75% of the plots had more than 70% of the basal area contributed by food species, and 50% of all plots had more than 90% of the total basal area contributed by food species. Basal area of food species was strongly positively correlated with the total basal area ( $R^2=.88, p<.001$ ).



**Fig 4.** Scatter plot of mean and coefficient of variation of basal area of food species

When calculated as a mean value per grid, the basal area of food species per plot varied between 2754.82 cm<sup>2</sup> and 15281.61 cm<sup>2</sup> (mean=8677.79±824.89 cm<sup>2</sup>),

and the coefficient of variation, between 30.17% and 110.74% (mean=57.24±5.14%).

The two variables were negatively correlated ( $R^2 = -.341$ ,  $p = .014$ ) (Fig 4).

#### Relationship between group parameters and basal area of food species

Total group size, adult male group size and adult female group size are negatively related to mean basal area of food species (Table 3). Adult male group size showed the most robust relationship, as indicated by the median  $p$ ,  $R^2$  and the fraction of significant regressions out of 500 iterations.

Total group size, adult male group size and adult female group size are positively related to coefficient of variation (CV) of basal area of food species (Table 3). Again, adult male group size shows the most robust relationship, with more than 50% of the variance accounted for by CV of basal area, as compared to only 25.9% in the case of adult females.

**Table 3.** Results of regressions between group attributes and mean and CV of basal area of food species

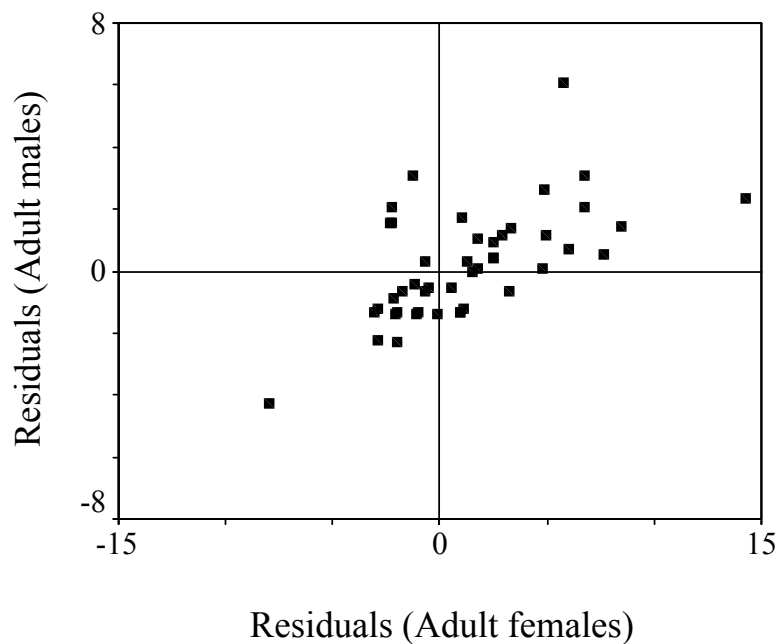
Variable	Predictor	Median $\beta$	Median $p$	Median $R^2$	Significant regressions out of 500
Total group size	Basal area	-12.424	0.019	.316	353
	CV	0.268	0.016	.328	353
Adult male group size	Basal area	- 2.444	0.004	.443	434
	CV	0.055	0.001	.512	460
Adult female group size	Basal area	-5.572	0.031	.273	297
	CV	0.111	0.037	.259	278

On normalizing adult male and adult female group size, and performing the same set of regressions, it was found that the slope obtained from regressions between

adult male group size and coefficient of variation of basal area of food species was .032, larger than what was obtained for adult female group size (slope=.016) ( $t=19.952, p<.0001$ ).

#### Relationship between adult males and adult females

When the effect of the CV of basal area of food species is removed using the median slope and intercept obtained from the regression equations, adult female and adult male group size are positively correlated ( $R=.609, p<.001$ ) (Fig 5).



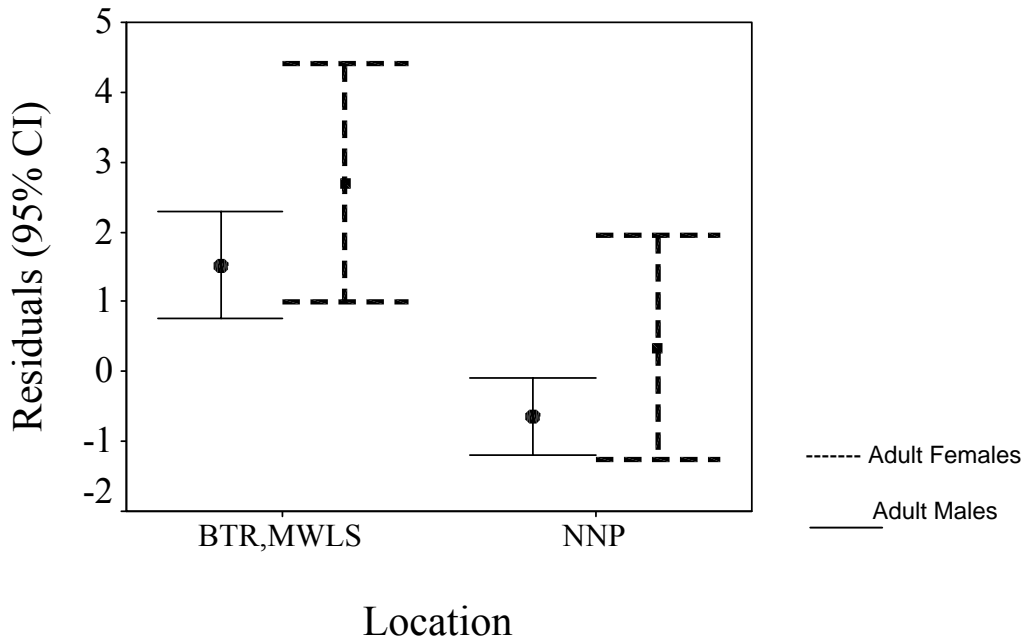
**Fig 5.** Scatter plot of residuals of adult male and adult female group sizes on removal of the effect of CV of basal area of food species

### Residual variation in adult male and adult female group size

The aforementioned residual values were further examined. This was found to be lower in Bandipur TR and Mudumalai WLS (mean=-2.69±.81 for adult females, and -1.52±.36 for adult males) as compared to Nagarahole NP (mean=-.34±.78 for adult females, and .65±.27 for adult males) ( $t=-2.1$ ,  $p=.048$  for adult females, and  $t=-4.823$ ,  $p<.001$  for adult males) (Fig 6).

### Distinction between Bandipur TR and Nagarahole NP

The field site in Bandipur TR, with Mudumalai WLS bordering it, is spatially separated from that in Nagarahole NP. These areas differ in all-male presence, with the proportion of all-male groups in Nagarahole NP being .423, and that in Bandipur TR and the neighbouring Mudumalai WLS being .113. The total basal area of Nagarahole NP (mean=12216.93±1148.39) is greater than that of Bandipur TR (mean=7327.69±2144.73) ( $t=3.386$ ,  $p=.005$ ). Though, basal area of the subset of food species is not significantly larger in Nagarahole NP ( $t=1.937$ ,  $p=.075$ ), the mean basal area of trees in Nagarahole NP (9595.95±1193.95 cm<sup>2</sup>) is greater than the mean basal area of Bandipur TR (mean=6456.99±822.79).



**Fig 6.** Residuals of adult male and adult female group sizes, on removal of the effect of CV of basal area of food species, in Bandipur Tiger Reserve (BTR) and Mudumalai Wildlife Sanctuary (MWLS), and Nagarahole National Park (NNP).

### Discussion

As has been mentioned earlier, three factors have a significant influence on group size and composition; resources, predation and social factors. For the common langur, distribution of resources seems to be the major determining factor on grouping. This is indicated by the positive relationship between the CV of basal area of food species and group size. This is in accordance with the prediction made at the beginning of the study, of increasing group sizes with increasing clumping of resources.

This result is significant in two aspects. One is regarding the folivore paradox. The reason the influence of resources has been so interesting is due to confusion about the existence of limitations imposed by resources on folivores (Snaith and Chapman 2005). This study taken along with other studies with supporting evidence (Chapman and Chapman 2000; Gillespie and Chapman 2001; Snaith and Chapman 2005), however, should convince any doubtful minds.

The second aspect is the use of distribution of the collective resource base in analyses. With the emergence of theories such as the ecological constraints theory, and with the complications associated with the measurement of distribution, distribution of resources has taken a backseat to resource abundance (Chapman and Chapman 2000; Chapman and Pavelka 2005; Snaith and Chapman 2005). Studies that have taken distribution into account have often dealt with individual food species (Koenig et al. 1998). What determines grouping, however, is not a single resource species, but the collective resource base. This has been evidenced by the data provided in this study.

With increasing food abundance, group size decreased, contrary to the prediction of the ecological constraints hypothesis. This indicates that food abundance is not a limiting factor in grouping. In spite of being only 28 out of a total of 68 species encountered in the plots, resources accounted for a large proportion of the total basal area, comprising more than 90% in 50% of the vegetation plots. According to Newton-Fisher et al. (2000), food is an important factor governing grouping in areas of low abundance, but not in areas of higher abundance. This could be a reason why resource abundance has not had a positive effect on the group sizes of the langurs in the sampled area. The negative relationship between abundance of resources and group sizes possibly arises as an artifact of the relationship between the group attributes and the distribution of resources, which is, in itself negatively correlated with resource abundance.

Resource abundance has a direct effect on the density of groups (Hanya et al. 2005). In accordance with this, langurs are found in higher densities of 33.4 animals per km<sup>2</sup> in Nagarahole NP, as compared to 16.4 animals per km<sup>2</sup> in Bandipur TR (Karanth et al. 2001).

Resources thus have an effect on the common langur in two ways. When abundance increases, langurs probably respond with an increase in density, though this is not evidenced by this study. Whether this is manifested as an increase in group size or by an increase in the number of groups becomes a consequence of resource distribution.

The difference that exists between Nagarahole NP on the one hand, and Bandipur TR, and Mudumalai WLS on the other, on the removal of the effect of resource distribution, is also striking. Groups in Nagarahole NP tend to have a smaller adult male group size than is expected by the distribution of food in the area, and Bandipur TR are larger.

The proportion of all-male bands to bisexual bands is higher in Nagarahole NP, indicating a higher risk of take-over, than Bandipur TR. Larger groups are more effective in preventing take-over, and the resulting act of infanticide (Chapman and Pavelka 2005), and thus, high risk of take-over would predict an increase in group sizes, which is contrary to the situation here. The risk of take-over, consequently, cannot explain this deviation from what is expected by resource distribution.

Leopard and tigers are important predators of the common langur (Karanth and Sunquist 1995). Camera trap studies show encounter rates of 1.73 per 100 trap nights in Nagarahole NP and 0.85 per 100 trap nights in Bandipur TR (Karanth et.al. unpublished data), and densities of 15.2 tigers per km<sup>2</sup> in Nagarahole NP as compared to 12 tigers per km<sup>2</sup> in Bandipur TR (Karanth et al. 2001). This implies a much larger predator presence in Nagarahole NP as compared to Bandipur TR. Predation risk has the effect of increasing group sizes for better vigilance (van Schaik et al. 1983), similar to the effect of increased risk of take-over. This also predicts a result that counters what has been observed.

Actual predation rates in the two areas, however, may not be as indicated by densities. It has been found that 28.58% of leopard kills in Bandipur TR are of common langurs (Andheria unpublished thesis), while only 14% have been found to be common langurs in Nagarahole NP (Karanth and Sunquist 1995). Predation by tigers do not vary so drastically, with 11.27% of individuals killed in Nagarahole NP being common langurs (Karanth and Sunquist 1995), compared to 9.18% in Bandipur TR (Andheria unpublished thesis). This should be treated with caution, however, as the situation in Nagarahole NP could have changed since the time of the study.

Borries et al. (2001) suggested a possible reason for multi-male groups in nutrition-poor areas and uni-male groups in nutrition-rich areas being the greater cost of infant loss in areas of poor nutrition availability. They have shown that life-history traits such as age at first parturition, gestation period, and lactation period are different in areas of differing resource abundance, making inter-birth intervals longer in areas of low resource abundance. Due to this, protection against loss of infants in areas of low nutrition abundance such as Bandipur TR, would be of great importance. This could be due protection against predation, which adult males are far more effective at as compared to adult females (van Schaik and Horstermann 1994) or, infanticide, which is also carried out by adult males (van Schaik 2000).

Independent of the effect of resources, adult males and females are strongly correlated. Adult males react to the environment more drastically and predictably than adult females, with more of the variance among males being explained by food distribution than females. This indicates the governance of males primarily by resources, rather than females. This is counter-intuitive in the light of the fact that it is believed that female fitness is associated more closely with resource abundance than adult males (Trivers 1972, in Fashing 2001). The reason for this is not clear.

We suggest, therefore, that in the common langur, resource distribution has a determining effect on the size and composition of groups. The abundance of resources does not play a major role in grouping; instead, it has a more direct effect on densities. Contrary to what is expected, resources have a stronger effect on adult males than adult females. There is no evidence of association independent of this effect to other factors such as the risk of predation or take-over. If these factors lead to variations in grouping, it is in combination with some latent effect that has not arisen in this study, such as the cost of infanticide caused by resource limitations. Ecology, thus, has a core role to play in grouping of these folivores, social factors and predation forming a blanket around this core.

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## **CHAPTER 2: Applicability of NDVI for quantifying langur resources: a study on the influence of resources on group size and composition of the common langur (*Semnopithecus entellus*)**

### **ABSTRACT**

Ecological research often demands a scale of study that can be difficult to achieve. One such subject of research is the influence of resources, in terms of abundance and distribution, on group size and composition of primates. This study intends to test the applicability of the simplest spectral vegetation index, normalized differential vegetation index (NDVI) as a surrogate for food resources of the common langur (*Semnopithecus entellus*) at a broad scale. Since NDVI has been found to correlate with canopy density and langur food trees form a large proportion of all trees present, NDVI was expected to correlate with langur resource. The study was conducted in Nagarahole National Park, Mudumalai Wildlife Sanctuary, and Bandipur Tiger Reserve, between January and May, 2006. Groups were opportunistically located and followed, in order to obtain reliable counts and compositional data. Data on resource abundance and distribution was collected from seventeen 1 km × 1 km grids, each containing twelve 25 m × 25 m plots. NDVI was extracted from satellite imagery (February, 2006). The relationship between mean NDVI and resource availability, contrary to expectations, was negative, probably due to the presence of an invasive shrub, *Lantana camara*. The relationship between mean NDVI and group attributes (total adult male, and adult female group size) depended on the scale of observation. At the scale of the entire study area, total and adult female group size exhibited a positive, though weak relationship with mean NDVI. When examined separately, a negative relationship was obtained in Mudumalai WLS, while none was obtained in Bandipur TR or Nagarahole NP. CV of NDVI was positively related to tree density.

The use of NDVI, thus, though advantageous, should be treated with caution, and any interpretation should be made mindful of all factors that influence it.

## **INTRODUCTION**

Researchers have long grappled with the patterns of grouping in primates, and the factors that influence them. One of the major influences on grouping is food resources. Resources have their effect on grouping in two ways, one is through abundance, and the other is the way these resources occur in space [Chapman & Chapman, 2000; Terborgh & Janson, 1986].

Resources, if limiting, selects against groups that have a high degree of within-group competition [Chapman & Chapman, 2000]. This sets a limit on the group size, which relaxes as the resources become more abundant in the environment. Thus, as resources increase, group sizes tend to increase as well [Chapman & Chapman, 2000].

Distribution has a more direct effect on primate groups. When resources are uniformly distributed, small groups are selected for. When they get clumped, resource patches become larger, making them more attractive to defend, and enabling the subsistence of larger groups [Johnson et al., 2002; Terborgh & Janson, 1986].

Opportunities to do justice to this question are provided by some primates showing wide variations in group sizes and composition [Koenig & Borries, 2001; Struhsaker et al., 2004]. However, the main problem associated with addressing this question has been one of scale. Scale forms an important factor that can hide or expose patterns in ecology [Bonabeau et al., 1999], and should be decided based on the ecological question. Difficulties associated with the acquisition of data on a scale large enough to get a complete hand on this question, spanning a large enough variety of habitats to get a complete range of resource abundances and variability, are tremendous. Primatologists have, in response to these difficulties, taken a smaller subset of habitats [Gillespie & Chapman, 2001], or compared across species [Chapman & Pavelka, 2005]. While these methodologies have shed some light on

these aspects of sociality, no single study has provided the entire repertoire of social groups of a species, and thus, no single study can present a complete picture. Comparisons across studies are problematic, due to differences in methodologies.

What is required, then, is a method that enables collection of data over a large enough scale to cover a substantial proportion of variation, or one that is standardized and can be compared across studies. One possibility is the use of remote sensing. Satellite imagery has, for this reason, attracted much attention from ecologists, especially in the realm of research on climate change [Pettorelli et al., 2005]. Comparing across satellites is also possible, but with caution, and if required, some parameterization [Soudani et al., 2006].

Satellite imagery allows the use of some ecologically interesting and meaningful variables, arising due to differences in reflectance of different light bands, standardized as spectral vegetation index (SVIs) [Soudani et al., 2006]. The most commonly used SVI is Normalized Differential Vegetation Index, (NDVI). NDVI takes into account the reflectance of light in the red and the near infra-red bands, and normalizes this range of values. Theoretically, NDVI can range from -1 to +1. Areas with photosynthetic aboveground biomass have a positive NDVI, which increases as the biomass increases. In reality, however, NDVI typically varies over a subset of its theoretical range, from -0.1 to 0.6 [Zinner et al., 2001].

The use of NDVI as a surrogate for photosynthetic biomass has been explored in a number of studies. These have dealt mostly with aboveground photosynthetic biomass [Gamon et al., 1995], canopy cover [Carreiras et al., 2006] primary productivity [Field et al., 1995], and leaf area index (LAI) [Carlson & Ripley, 1997; Turner et al., 1999] as the ground-level variables, which have found a positive trend between the two. However, this positive trend saturates in areas with high

quantities of aboveground photosynthetic biomass, and does not hold for areas of very sparse vegetation either [Soudani et al., 2006]. This limits the applicability of NDVI to areas of intermediate photosynthetic biomass.

In spite of these advantages, however, ecology has largely used NDVI as a response variable [Pettorelli et al., 2005]. A large number of studies till recently have explored the relationship of NDVI and other spectral indices with vegetative variables. Studies have also dealt with the response of SVIs to global [Nemani et al., 2003], as well as local climate changes [Wang et al., 2001]. Studies that use SVIs as a predictor variable are more recent [Pettorelli et al., 2005]. These have examined the correlations between SVIs and demographic parameters [Pettorelli et al., 2006], biodiversity [Bawa et al., 2002], and distribution of species [Anderson et al., 2004]. SVIs are also useful in the realm of ecological monitoring [Stoms & Hargrove, 2000]. They have been modelled to estimate net terrestrial primary productivity, in India [Chhabra & Dadhwal, 2004], and biomass [Roy & Ravan, 1996].

Primatologists have also started paying some attention to SVIs as potentially useful tools. [Zinner et al., 2001] observed higher values of NDVI in home ranges of baboons, associating habitat selectivity and NDVI. Distribution of primate species and NDVI has received some attention [Zinner et al., 2002]. The use of NDVI in primate behavioural studies have also been explored by [Pintea et al., 2002]. Phillips et al. [1998] attempted to relate the ranging behavior of capuchin monkeys (*Cebus spp.*) and bearded sakis (*Chiropotes satanas*) to the dispersion and availability of food resources, using GIS techniques. However, the attempt was unsuccessful due to the inability to pick up satellite signals via Geographic Positioning Systems (GPS).

This study aims to take a step further, and explore the use of NDVI in primate ecology. NDVI is proposed as a surrogate for food resources of a colobine, the

common langur. Since a study has found the food resources of this species to make up a large proportion the total number of trees and species present (Chapter 1), and thus, the food resource availability to be highly correlated with total tree density, and basal area, this forms a reasonable possibility. It is also expected, from results of the abovementioned study (Chapter 1, p), that group size will be negatively correlated with mean NDVI, representing resource abundance, and positively correlated to the coefficient of variation of NDVI at a particular grid cell size, representing clumping of resources.

The objective of the study is thus twofold. One is to examine the relationship between NDVI and resource availability as measured at ground-level. Two factors have been explored. One is the use of average NDVI as an index of resource abundance. The other is the use of the coefficient of variation of NDVI as an index of clumping of resources. If the two were correlated, then the use of NDVI as a surrogate for resource availability is justified. The second objective is to examine whether NDVI explains the variation in group size and composition of the common langur, regardless of its correlation with food resources. The mean NDVI of all pixels around the location of groups would give an index of resource availability, while the coefficient of variation would give an index of spatial heterogeneity.

## **METHODS**

### **Study Area**

Data on group size and ground data on vegetation was collected between January and May, 2006, in parts of Nagarahole National Park (NP), Bandipur Tiger Reserve (TR), and Mudumalai Wildlife Sanctuary (WLS). Descriptions of the topography, climate and major floral and faunal species are given in Chapter 1.

## Field Methods

### *Group Composition*

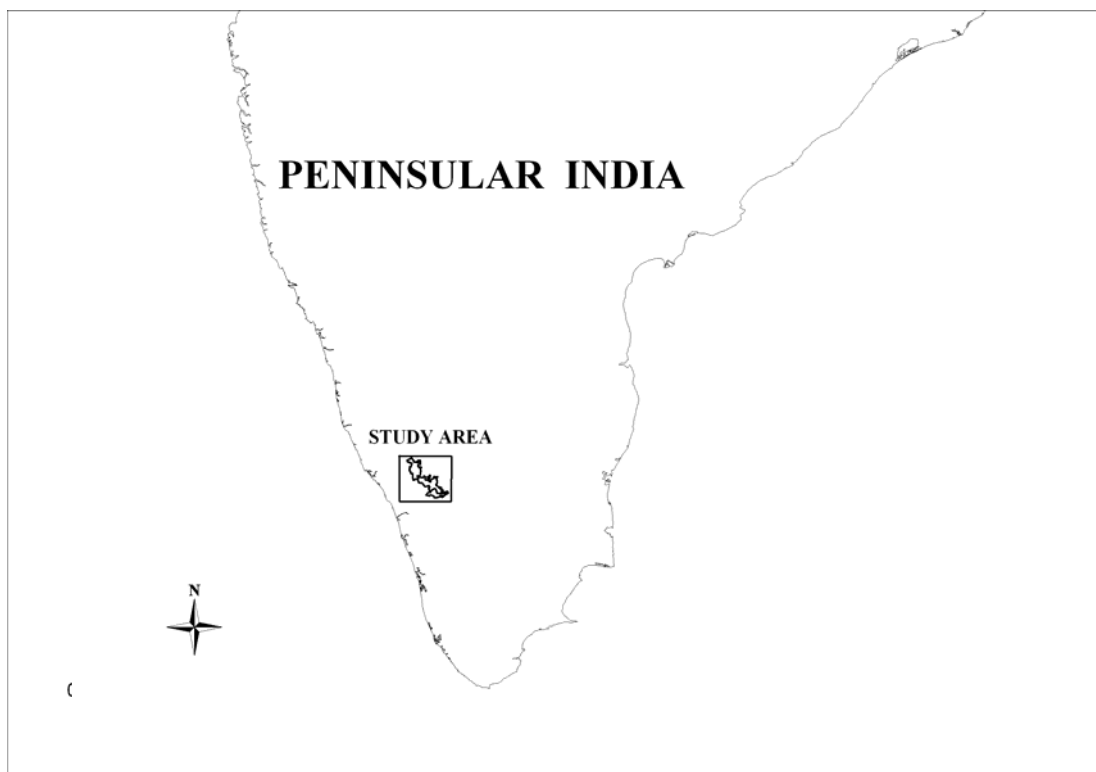
The study area had an elaborate network of roads, which facilitated location of groups. Once located, each group was followed for the time necessary to obtain reliable counts. The langurs were classified into age-sex categories (Table I). Locations of all groups were marked on a Garmin 72XL Geographic Positioning System. The group attributes used for analysis included total group size, adult male group size, and adult female group size.

**TABLE I.** Classification of group members

<b>Category</b>	<b>Description</b>
Adult male	Sexually and socially mature males, with well developed secondary sexual characteristics
Adult females	Sexually and socially mature females, with well-developed secondary sexual characteristics
Sub-adults	Members of the group that are sexually, but not socially mature. As far as possible, sub-adults were classified into males and females.
Juveniles	Sexually immature weaned members of the group,
Infant Stage 2	Infants with white pelage.
Infant Stage 2	Infants with black pelage. These members are mostly found with an adult female.

## Vegetation

A previously laid grid layer of dimensions 1km × 1km (ATREE, unpublished data) was used for Nagarahole NP and Bandipur TR. For Mudumalai WLS, a grid layer of the same dimensions was laid, using the software MapInfo 7.5 SCP [MapInfo Corporation, 2003]. Seventeen grids spread over the study area were chosen from this layer, based on the location of groups (Fig. 1).



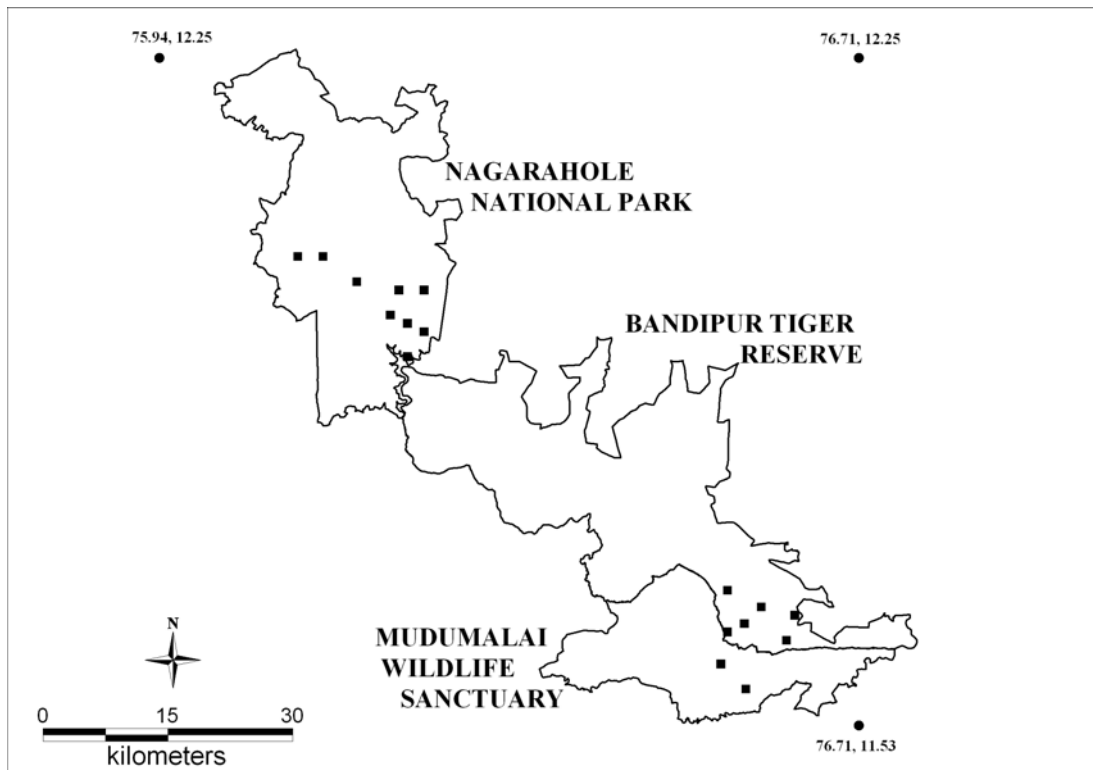


Fig. 1. Locations of the seventeen 1km × 1km vegetation grids

Within each chosen grid, twelve 25 m × 25 m plots were randomly chosen. The locations of these were obtained from MapInfo 7.5 SCP [MapInfo Corporation, 2003], and these were then located on ground using a GPS. Within each plot, all trees with GBH (girth at breast height)  $\geq 30$ cm were enumerated and identified. The GBH of each was noted. Canopy cover was estimated for each plot using a canopy densiometer. Total basal area was calculated for each plot.

A list of food tree species of the common langur, compiled from previous studies in different areas [Hrdy, 1977; Koenig et al., 1998; Palaniappan, 1987; Ripley, 1970; Tewari, 1991] and *ad libitum* feeding observations made during this study was used to identify food species of the common langur. The subset of food species in each plot was used for analysis.

For each of the 17 grids, the mean and coefficient of variation of the basal area of food trees per plot were calculated. Mean basal area of the food trees was taken as

an index of resource abundance. Measures derived from the diameter at breast height have been found to accurately predict leaf biomass [Chapman & Pavelka, 2005].

The co-efficient of variation of basal area among plots that fell within each grid gives an index of heterogeneity within that grid. This measure of heterogeneity is used as an index of clumping. Since this is taken collectively for all food resources, it is an index of clumping of food resources as a whole, and not of individual species.

### **Extraction of NDVI**

Satellite imagery from satellite IRS – P6, sensor LISS-III, date of pass 27<sup>th</sup> of February 2006 was used. This coincided with the period of collection of ground-level data. The extent of the scene was 141 X 141km, and the resolution was 23.5 X 23.5m. The image has reflectance of four bands, blue, red, near infra-red and short-wave infra-red.

The image was georeferenced using the RESAMPLE module of the software Idrisi Kilimanjaro [Clark Labs, 2004]. A previously georeferenced image of the same area was used as a reference image. Thirty ground control points (GCPs) were chosen, mainly at road intersections, and dams, to achieve a root mean square error of 0.52 pixels.

The georeferenced layers were then used to calculate an NDVI layer, using the formula

$$NDVI = (\rho_{NIR} - \rho_{RED}) / (\rho_{NIR} + \rho_{RED})$$

The NDVI values of all pixels located within the seventeen grids were extracted. Measure of central tendency (mean and median), and of variation (standard deviation and coefficient of variation) were calculated for each grid.

Home ranges were obtained from previous studies from elsewhere [Hrady, 1977; Srivastava & Dunbar, 1996]. Assuming these to be circular, the average radius was calculated to be 738 m. Using this as the radius, a circular area was demarcated around the location of each group. NDVI values of all pixels lying within this buffer were extracted for all groups.

### **Statistical Analysis**

Ground-based vegetation parameters (number of trees per plot, number of food trees per plot, number of species per plot, number of food species per plot, total basal area per plot, basal area of food species per plot; aggregated as a mean value for each grid) was tested for correlation with the mean and CV of NDVI, to test the use of NDVI as a surrogate variable for resource availability and distribution of the common langur.

NDVI values were tested with group attributes, namely total, adult male and adult female group size for correlation. This was done at two levels. It was first averaged for an entire area, that is for Nagarahole NP, Bandipur TR and Mudumalai WLS, and then analyzed separately in each of these areas.

All statistical tests were carried out using statistical software SPSS 11.5 [SPSS, 2002].

## **RESULTS**

### **Group Size and Composition**

In total, 232 groups were located, out of which reliable count and compositional data were obtained for 94 bisexual groups (Fig. 2). These varied in size between 7 and 40 with a mean of 18.61 ( $\pm 7.1$ , S.E. of mean) and a median of 18.5. (Fig. 3a). The number of adult males in a group varied between 1 and 8 (mean=2.59 $\pm$ .15) (Fig. 3b),

and the adult females between 1 and 20 (mean=8.59±.35) (Fig. 3c). Adult females accounted for maximum variation in group size ( $R^2=.547$ ). Of the 232 groups, 35 were all-male groups. The size of all-male groups ranged from 6 to 16, with a mean of 7.78 ( $\pm.563$ ), and a median of 7. The ratio of all-male groups to bisexual groups was .058 in Mudumalai WLS, .167 in Bandipur TR, .423 in Nagarahole NP.

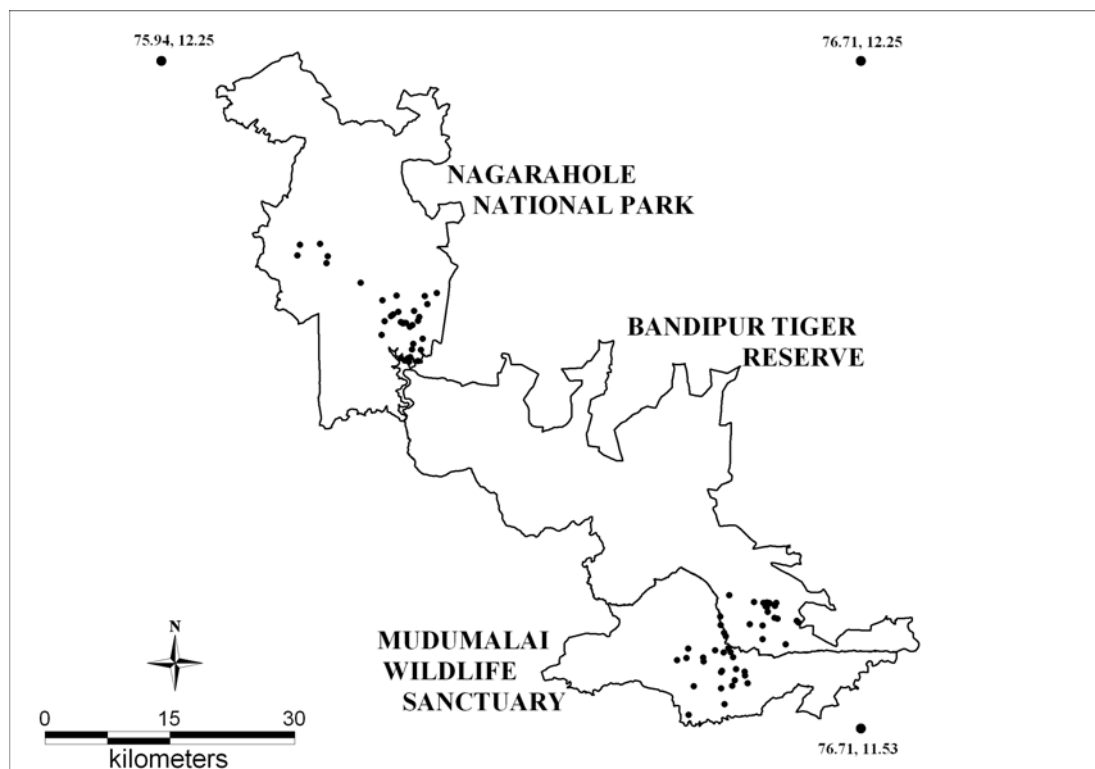


Fig. 2. Locations of the 94 groups for which reliable counts were obtained

## Vegetation

Number of trees per plot varied between 0 and 44 (mean=13.58±.56, median=12.5). Between 0 and 13 species (mean=5.24±.17, median=5) were encountered in each plot. Basal area varied from 0 to 32749.66 cm<sup>2</sup> (mean=10501.02±456.38 cm<sup>2</sup>, median=9652.88 cm<sup>2</sup>).

Out of 68 tree species encountered, 22 species have been reported as food species of the common langur from studies elsewhere. An additional six species (*Acacia concinna*, *Dalbergia latifolia*, *Garuga pinnata*, *Pterocarpus marsupium*,

*Radermachera xylocarpa* and *Terminalia alata*) were recorded as food species based on observations made during the present study. A list of food species encountered in plots is given in Table II.

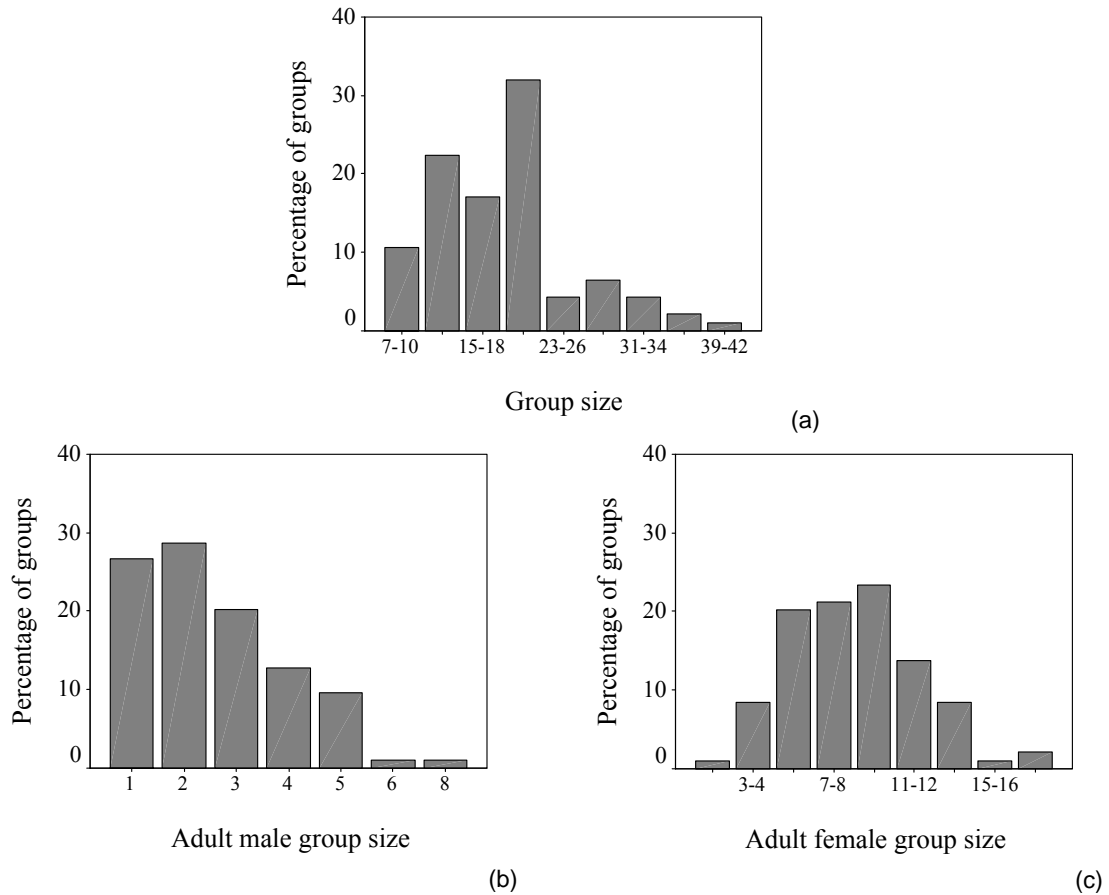


Fig. 3. Frequency distribution of **a**: total **b**: adult male and **c**: adult female group sizes for all 94 groups

The number of food trees in a plot varied from 0 to 43 (mean=10.83±.53, median=10), and the number of food species from 0 to 8 (mean=3.72±.12, median=4). Basal area of food trees ranged between 0 and 31585.03 cm<sup>2</sup> (mean=8612.58±410.85 cm<sup>2</sup>, median=7849.41 cm<sup>2</sup>).

Food trees formed between 0 and 100% of all trees within plots. In 75% of the plots, food trees comprised more than 65% of all trees, and food species comprised more than 60% of all species. 75% of the plots had more than 70% of the basal area contributed by food species, and 50% of all plots had more than 90% of the total basal

area contributed by food species. Basal area of food species was strongly positively correlated with the total basal area ( $R^2=.88$ ,  $p<.001$ ).

**TABLE II.** Food species encountered in vegetation plots

<i>Ficus benghalensis</i> <sup>a,b,c,d</sup>	<i>Cassia fistula</i> <sup>a,b</sup>
<i>Ficus religiosa</i> <sup>a,b,c,d</sup>	<i>Mallotus philippensis</i> <sup>d</sup>
<i>Bauhinia racemosa</i> <sup>a,c</sup>	<i>Randia dumetorum</i> <sup>a</sup>
<i>Dalbergia latifolia</i>	<i>Terminalia alata</i>
<i>Albizia lebbek</i> <sup>c,d</sup>	<i>Terminalia bellirica</i> <sup>c,d,e</sup>
<i>Bombax ceiba</i> <sup>d</sup>	<i>Mangifera indica</i> <sup>a,c</sup>
<i>Lagerstroemia parviflora</i> <sup>d</sup>	<i>Butea monosperma</i> <sup>a,d</sup>
<i>Ziziphus xylopyrus</i> <sup>d</sup>	<i>Emblica officinalis</i> <sup>d</sup>
<i>Ziziphus oenoplia</i> <sup>a</sup>	<i>Syzygium cumini</i> <sup>a,b,d</sup>
<i>Premna tomentosa</i> <sup>a</sup>	<i>Radermachera xylocarpa</i>
<i>Garuga pinnata</i>	<i>Schleichera oleosa</i> <sup>a,b</sup>
<i>Bridelia retusa</i> <sup>a,b</sup>	<i>Acacia concinna</i>
<i>Diospyros montana</i> <sup>a</sup>	<i>Anogeissus latifolia</i> <sup>d</sup>
<i>Adina cordifolia</i> <sup>a,b</sup>	<i>Pterocarpus marsupium</i>

Sources : **a**: [Ripley, 1970] **b**: [Hladik, 1977] **c**: [Hrdy, 1977] **d**: [Tewari, 1991] **e**: [Koenig et al., 1998]. 6 species were identified as food species based on observations made during the course of this study.

When calculated as a mean value per grid, the basal area of food species per plot varied between 2754.82 cm<sup>2</sup> and 15281.61 cm<sup>2</sup> (mean=8677.79±824.89 cm<sup>2</sup>), and the coefficient of variation, between 30.17% and 110.74% (mean=57.24±5.14%).

The two variables were negatively correlated ( $R^2= -.341$ ,  $p=.014$ ) (Fig. 4).

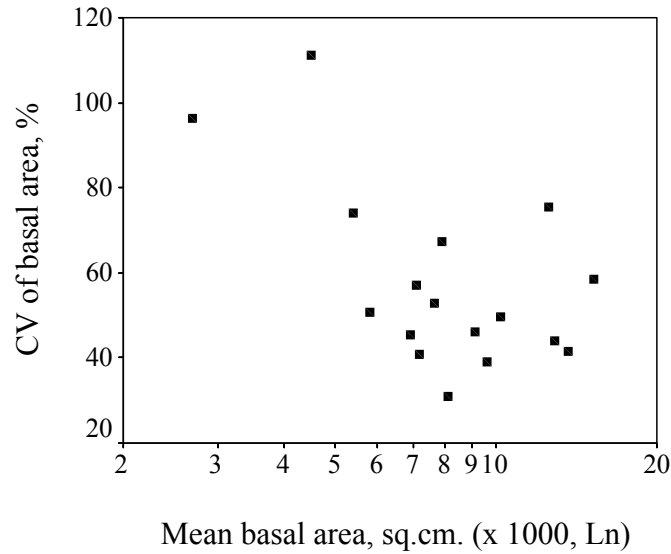


Fig. 4. Scatter plot of mean and coefficient of variation of basal area of food species

### NDVI

NDVI averaged for each grid gave values between .1286 and .3081 (mean = .205 ± .014, median = .1892) (Fig. 5a). When aggregated as a coefficient of variation (CV) for each grid, it ranged from 20.15% to 45.95% (mean ± SE = 31.78 ± 2.03%, median = 29.53%) (Fig. 5b).

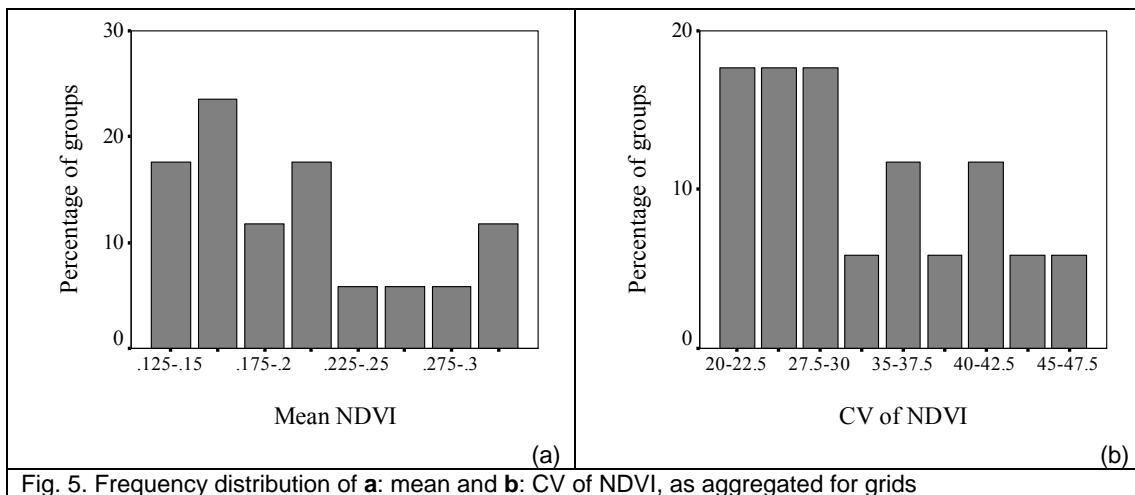


Fig. 5. Frequency distribution of **a**: mean and **b**: CV of NDVI, as aggregated for grids

Mean NDVI, when averaged areas of radius 738 m, centering each group, varied between .0779 and .3297, with a mean of .2077 (± .0055, SE of the mean) and a median of .1994 (Fig. 6a). The CV of NDVI varied between 20.88% and 205.78%

(mean  $\pm$  SE =  $38.34 \pm 2.25\%$ , median = 34.85%). However, 90% of the groups had CV values between 20.88% and 48.09% (Fig. 6b).

### NDVI aggregated for grids

The results of regressions between NDVI and vegetation parameters obtained from ground-based data collection are given in Table III. Mean NDVI was negatively correlated with mean basal area of all and of food species (Fig. 7), but did not show any relationship with the other variables. CV of NDVI was positively correlated with the number of trees, and of food trees per plot (Fig. 8).

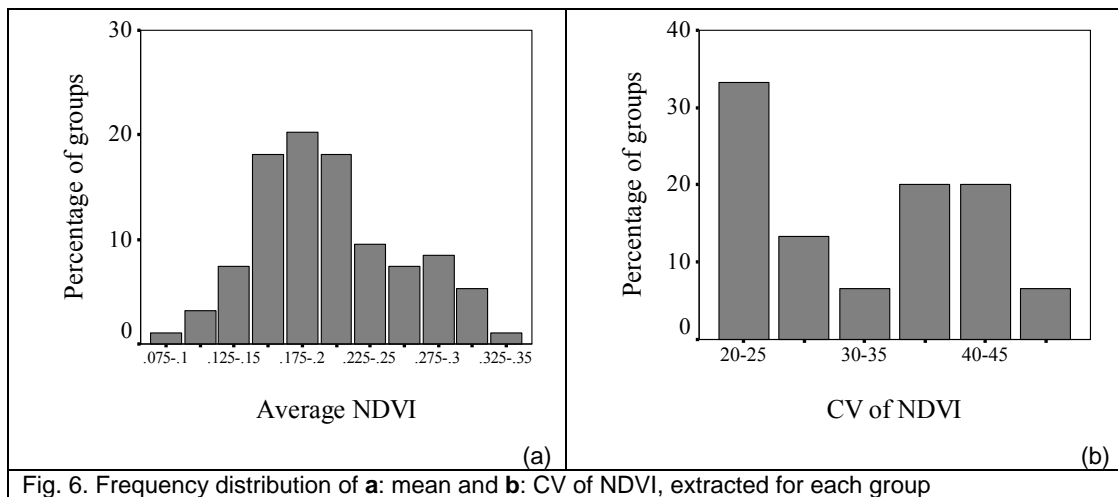


Fig. 6. Frequency distribution of a: mean and b: CV of NDVI, extracted for each group

**TABLE III.** Results of regressions between ground-based vegetation parameters and mean and CV of NDVI

Variable	Predictor	$\beta$	$p$	$R^2$
Number of trees	Mean NDVI	-.439	.078	.193
	CV of NDVI	.635*	.006	.403
Number of food trees	Mean NDVI	-.387	.125	.150
	CV of NDVI	.731*	.001	.534
Mean number of species per plot	Mean NDVI	-.326	.201	.106
	CV of NDVI	-.097	.711	.009
Mean number of food species per plot	Mean NDVI	-.261	.311	.068
	CV of NDVI	-.033	.901	.001
Mean basal area of all trees per plot	Mean NDVI	-.513*	.035	.264
	CV of NDVI	.036	.892	.001
Mean basal area of food trees per plot	Mean NDVI	-.515*	.034	.265
	CV of NDVI	.250	.334	.062

Significant relationships are indicated with an \* ( $p < .05$ )

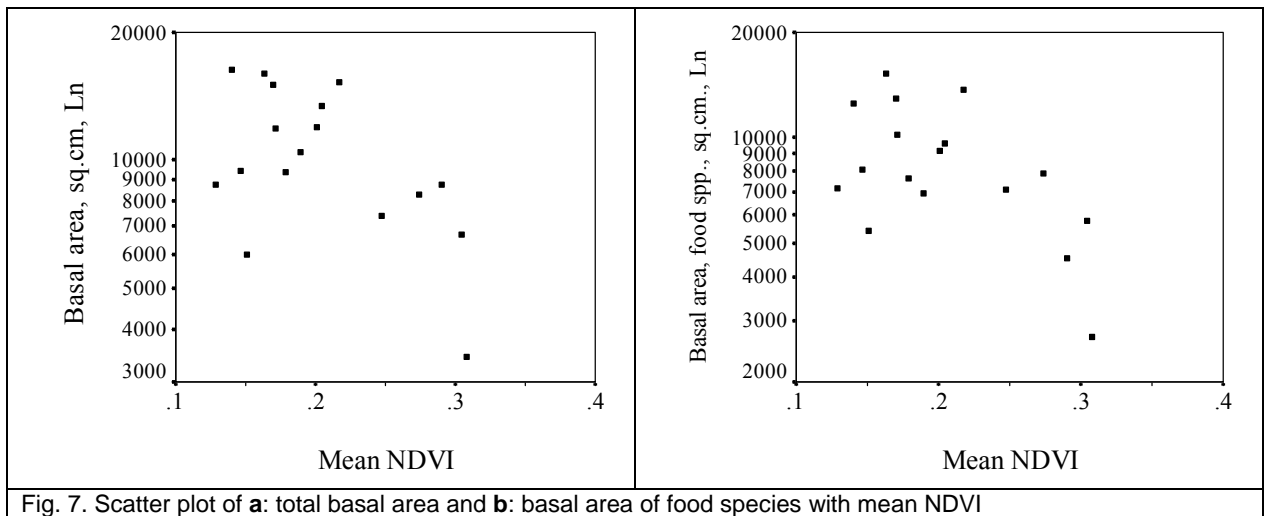


Fig. 7. Scatter plot of **a**: total basal area and **b**: basal area of food species with mean NDVI

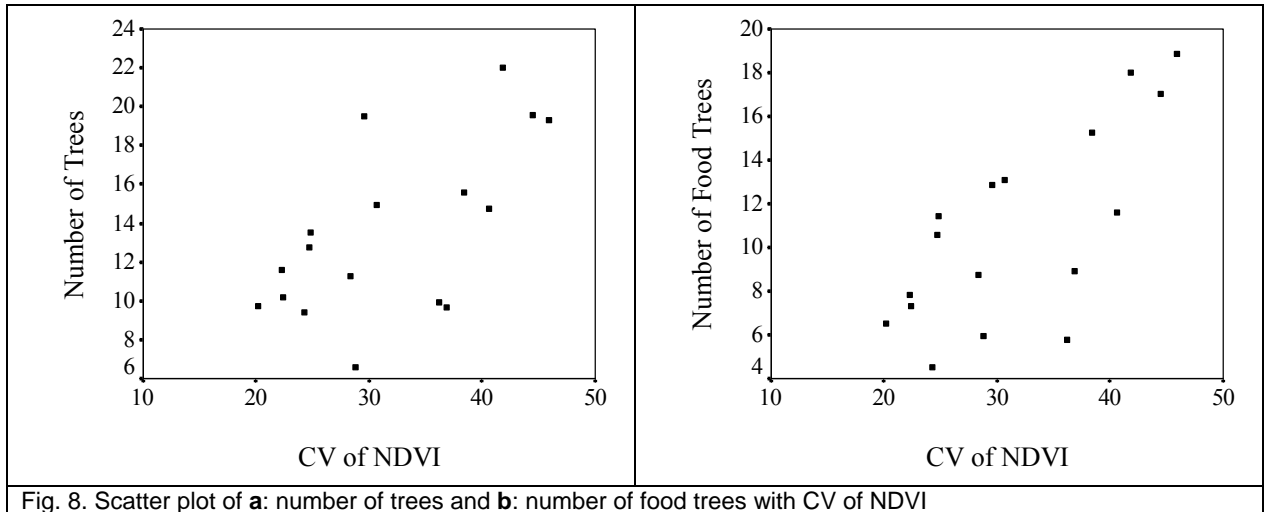


Fig. 8. Scatter plot of **a**: number of trees and **b**: number of food trees with CV of NDVI

### NDVI and group sizes examined per grid

Group sizes aggregated over grids as a median was positively correlated with mean NDVI ( $\beta = .532, p = .028, R^2 = .284$ ) (Fig. 9). It did not share any relationship with adult male or adult female group size, taken separately. CV of NDVI did not hold any relationship with group attributes.

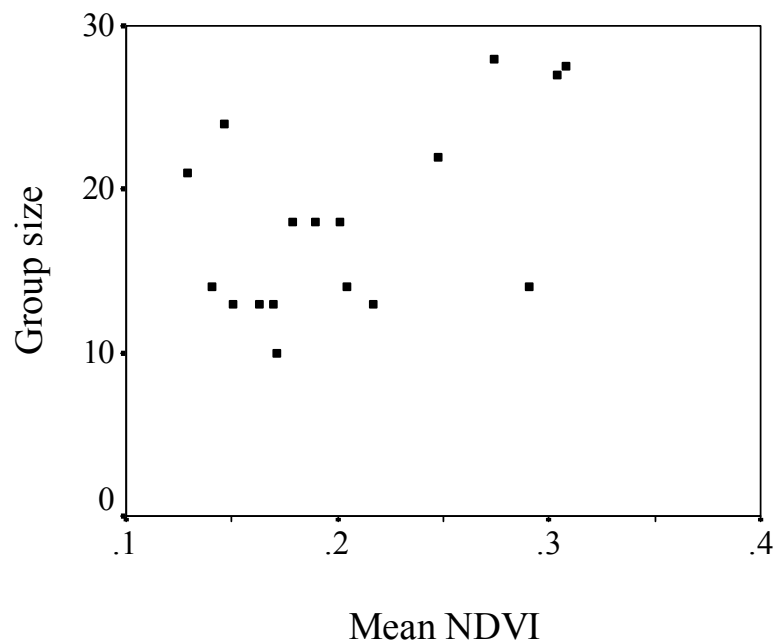


Fig. 9. Scatter plot of median group size and mean NDVI, aggregated for grids

### NDVI examined for all groups

NDVI varied significantly between protected areas ( $F = 32.697, p < .001$ ), Bandipur TR (mean =  $.26 \pm .0107$ ) having the highest, followed by Mudumalai WLS (mean =  $.2109 \pm .0055$ ), and then by Nagarahole NP (mean =  $.1723 \pm .0068$ ). The same was observed for group sizes as well (Table IV).

**TABLE IV.** Results of ANOVA between PAs, and measures of central tendency (mean NDVI, and median group parameters) for Bandipur TR (BTR), Mudumalai WLS (MWLS), and Nagarahole NP (NNP).

Variable	F	p	BTR	MWLS	NNP
Mean NDVI	32.697	<.0001	.26	.2109	.1723
Total group size	30.325	<.0001	24	18	14
Adult male group size	40.888	<.0001	4	3	1
Adult female group size	10.196	.0001	10	9	6

Within Nagarahole NP and Bandipur TR, average NDVI did not hold any relationship with group sizes. However, within Mudumalai WLS, it exhibited a weak negative relationship with group size ( $\beta = -.444, p = .009, R^2 = .197$ ) (Fig. 10a), with adult male group size ( $\beta = -.409, p = .016, R^2 = .168$ ) (Fig. 10b), and nearly so for adult females, though not significant ( $\beta = -.336, p = .052, R^2 = .113$ ).

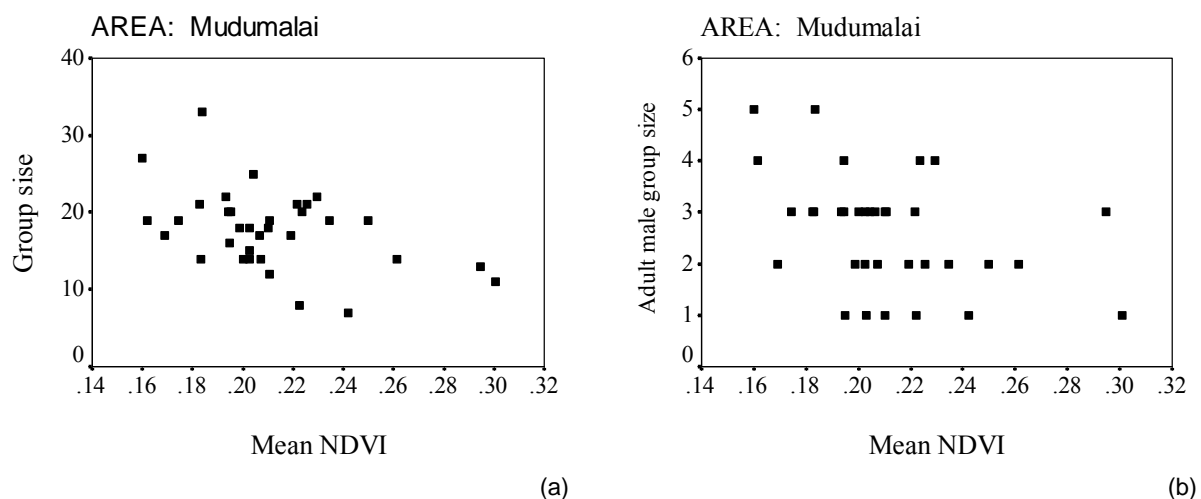


Fig. 10. Scatter plot of **a**: total and **b**: adult male group size with mean NDVI for Mudumalai WLS

All 94 groups taken together, mean NDVI shared a positive relationship with group size ( $\beta = .303$ ,  $p = .003$ ,  $R^2 = .092$ ) (Fig. 11a), but explained only a very small fraction of its variation. The same was seen with adult male group size ( $\beta = .348$ ,  $p = .001$ ,  $R^2 = .121$ ) (Fig. 11b), but not with adult female group size ( $\beta = .082$ ,  $p = .434$ ,  $R^2 = .007$ ). CV of NDVI did not show any relationship with any of the group attributes.

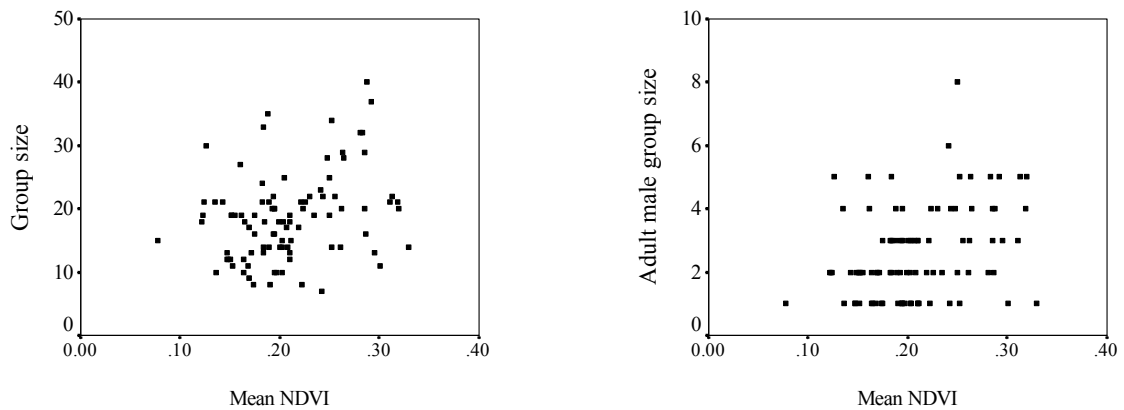


Fig. 11. Scatter plot of **a**: total and **b**: adult male group size with mean NDVI for all groups

## DISCUSSION

There is no doubt of the advantages associated with the use of remote sensing in ecological studies [Pettorelli et al., 2005]. The reason it has not been used more frequently, and for a wider range of studies to date could be the lack of established interpretability of indices derived from remote sensing [Carlson & Ripley, 1997; Gamon et al., 1995; Soudani et al., 2006].

It has been stated earlier that NDVI is an index to be dealt with carefully [van Leeuwen et al., 2006]. The relation that this index shares with above-ground photosynthetic biomass or leaf area index (LAI) saturates beyond a threshold [Carlson & Ripley, 1997]. The area in question is a deciduous forest, however, and this is probably not the reason for the lack of positive relationship between NDVI and basal area.

Though studies have shown very strong correlation between canopy cover and SVIs [Carreiras et al., 2006], this should be treated with caution, because it is dependent on the under-storey as well as canopy. More accurate is to state that above-ground photosynthetic biomass, rather than canopy cover, is positively correlated with certain SVIs such as NDVI [Gamon et al., 1995].

The undergrowth in the study area is, in many areas, an invasive shrub, *Lantana camara*. The density of this invasive is extremely high in certain areas, especially Bandipur TR, where occupancy-based estimates indicate .96 ( $\pm$ .03) occupation by *Lantana* (Krishna, unpublished thesis). It is highly likely that this is one of, if not the only, reason NDVI in Bandipur TR shows high values. Due to this, areas that actually have lower canopy biomass, have high NDVI values, making the relationship between NDVI and basal area negative.

In spite of this, the NDVI does show a relationship with group attributes. This relationship is in a direction opposite to what was expected, based on an earlier study (Chapter 1), which reports a negative relationship between group attributes and resource abundance.

Scale, as mentioned earlier is of utmost importance [Bonabeau et al., 1999]. The results obtained here are completely dependant on scale. In fact, whereas NDVI and group attributes vary in the same direction at the level of PAs, at the local scale of Mudumalai WLS, contrary to this, the two are negatively correlated.

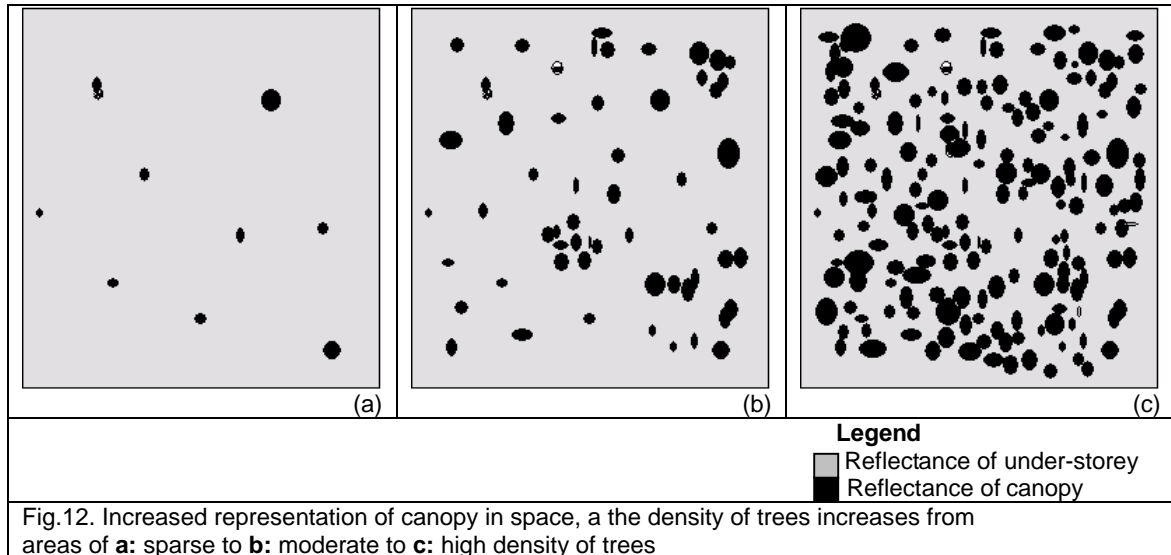
At the local scale, in areas like Mudumalai WLS, where undergrowth density does not vary to a large extent, mean NDVI probably reflects basal area. As a result, NDVI has a negative relationship with group size, as expected from earlier results (Chapter 1).

The reason for the positive relationship of total group size with NDVI at a larger scale, is more difficult to understand. It may be because of two reasons. One is a gradual decline of densities of *Lantana camara*, by coincidence, or otherwise, in areas of higher canopy cover. This is likely as the field sites, being part of a contiguous stretch of forest, are along a rainfall gradient.

An alternative explanation for this is that mean NDVI is actually a good indicator of food abundance of langurs, and at a large scale, this is the factor that affects group size [Chapman & Chapman, 2000]. This, however, is contrary to supporting evidence from ground-based methods, NDVI being, for one negatively related to basal area, and basal area, in itself being negatively related to group size (Chapter 1).

CV of NDVI positively correlated with the number of trees. Both the canopy and understorey contribute to NDVI. This would not have been the case in areas where grass formed the understorey, the contribution of grass to NDVI being very low [Krishnaswamy, 2004 67 /id}. However, the understorey of these areas is largely formed by the invasive shrub, *Lantana*. The leaf area index of *Lantana* is likely to be high, and thus, so is its contribution to NDVI. This is high enough to override canopy reflectance in areas of low tree density. From areas of extremely sparse trees, to areas of higher tree density, the reflectance of trees increase (Fig. 12). In areas of low tree density, therefore, the NDVI within a grid cell is homogenous in reflecting mostly the spectral signature of the shrub layer. As the tree density increases, NDVI of both the canopy and the under-storey are represented, and CV of NDVI within this grid cell, as a result, increases. As tree density increases even further, the CV is expected to saturate, and then decrease, as the exposure of understorey drops to very low levels. At these levels, NDVI homogeneously represents reflectance of the canopy. Thus, at

lower levels of tree density, when the under-storey is largely reflected in NDVI values, mean NDVI doesn't have the expected relationship with basal area of food species. At higher densities of trees, NDVI reflects canopy cover, and at these densities, the relationship between NDVI and basal area is expected to hold.



NDVI may not be, in itself, an ideal index for all ecological studies. While applicable in some cases, meaningful explanations can come out of its use only with a complete understanding of all factors that affect it. Latent factors, with overriding influence on NDVI might result in hiding a pattern, and as has been seen in this study, the creation of a pattern that, on closer inspection is found not to exist. In areas where the undergrowth is grass, with low NDVI, NDVI will not reflect, even exposed understorey to such an extent. However, representation in NDVI of *Lantana camara* at the densities at which it is found in these areas, overrides canopy reflectance. It might be a better option to examine other SVIs, as the situation suggests, or even use single bands in these cases. If spectral signatures of certain weeds or plants are available, of course, this is the best available option, and should be considered for use. Whatever the option in hand, the use of SVIs should be treated with caution and preferably ground-truthed before use in ecological studies, as a double sampling

technique. Once this is carried out, the use of these indices becomes desirable in allowing for extensive sampling in a relatively short time interval.

### **ACKNOWLEDGEMENTS**

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## CONCLUSIONS

There has been much debate on determinants of group size and composition of primates. For the common langur, resource distribution plays this role. As resources become more clumped, larger groups of langurs occupy the resource patches formed. Resource density has the effect of increasing the density of animals, rather than increasing group size. Surprisingly, adult males follow resources more predictably than adult females. Both adult males and females may also react to presence of predators and all-male groups, but no evidence of this arose from this study.

The reflectance of invasive shrubs like *Lantana camara* has an overriding influence on NDVI, masking the effect of canopy reflectance. Thus expected pattern of a positive correlation between NDVI and basal area of food species was not observed, and in fact, a negative trend was observed. The relationship of NDVI with group attributes was dependant on the scale of observation. Overall, NDVI was a weak predictor of group size.

Latent factors, with overriding influence on NDVI might result in hiding a pattern, or, as has been seen in this study, the creation of a pattern that, on closer inspection is found not to exist. The use of SVIs should thus, be treated with caution and preferably ground-truthed before use in ecological studies, as a double sampling technique. Once this is carried out, the use of these indices becomes desirable in allowing for extensive sampling in a relatively short time interval.