Structure and composition of rainforest floor amphibian communities in Kalakad–Mundanthurai Tiger Reserve

Karthikeyan Vasudevan[†,‡], Ajith Kumar* and Ravi Chellam[†]

[†]Wildlife Institute of India, P.O. Box 18, Dehradun 248 001 India
*Salim Ali Centre for Ornithology and Natural History, Anaikatti P.O., Coimbatore 641 108, India

Forest floor amphibian communities in the contiguous rainforest of Kalakad–Mundanthurai Tiger Reserve were sampled using quadrats, in order to enumerate factors that govern their distribution. A sampling protocol using adaptive cluster sampling provided data far superior to that from conventional random placement of quadrats. Distance from water along with other habitat parameters determined the local distribution of forest floor amphibians. Multi-species clusters of amphibians were identified along the edge of the hill streams. There were variations in the number of primary plots with amphibians, cluster size, and species richness in a cluster among the three sites sampled (Sengaltheri, Kannikatti and Kakachi) and to a lesser extent between the two seasons (dry and south-west monsoon). Sengaltheri and Kannikatti had a community dominated by *Rana temporalis*, in contrast Kakachi was *Micrixalus* dominated. Only 32 species were recorded during the study, suggesting low richness in any locality along the Western Ghats.

AMPHIBIANS have high species richness and endemism in India, with two major centres of distribution, north-east India and the Western Ghats[1,2]. It is in the latter that amphibian species richness and endemism are highest. Out of the 216 species in India, 120 species occur in the Western Ghats, with 93 endemics[3]. Species richness and endemism are notable among some taxa, e.g. 14 of 16 species of limbless amphibians (Caecilians), 29 out of 35 species of *Rhacophorus* or gliding frogs, and 35 out of nearly 50 species of Ranids[3]. The majority of the species occur in the rainforest and almost all the endemics are confined to it. Several species are represented by single locality records, dating back up to 100 years, e.g. *Rhacophorus lateralis*[4]. The taxonomic status of many species, of the genus *Philautus* and of Ranids are even now unresolved[5]. The life history, microhabitat preference, and the factors affecting the distribution of most species are unknown. The amphibians in India are beginning to be studied in detail[4], and species are being discovered even now[6].

Extensive deforestation in the Western Ghats over the last two centuries has not only resulted in the large-scale loss of forest cover, but has also caused the fragmentation of the remaining habitat into numerous isolated patches[7]. The anomalous distribution pattern of amphibians[8] has major conservation implications in the context of isolated populations, and for extinction proneness especially due to habitat loss and fragmentation. A recent assessment based on the revised IUCN criteria showed that nearly 57% of the amphibians in India are 'threatened', with the Western Ghats having the highest number (49) of the 'threatened species'[3]. To implement conservation programmes for amphibians it is important to understand the factors that control their diversity in the region.

Nair[7] describes Ashambu hills as having 'some of the best tropical moist forest in the Western Ghats, less than 100 km^2 is totally undisturbed'. Kalakad–Mundanthurai Tiger Reserve (KMTR, 895 km^2, 8º25′ to 8º53′ N and 77º10′ to 77º35′ E) provides this unique habitat, relatively undisturbed and over a large area of approximately 400 km^2 (ref. 9). Hence, it was chosen as our study area. The wet evergreen forests in these mountain ranges are well known for their diverse fauna and flora. Middle elevation wet evergreen forests (600 to 1200 m above mean sea level) at Sengaltheri, Kakachi and Kannikatti within the reserve were chosen for intensive sampling of the contiguous forest. These sites represent three different drainages within the reserve.

The study area experiences three seasons, the north-east monsoon extending from September to December, followed by the dry season during January–May, and the south-west monsoon period from June to August. The peak rainy season is October to December along the eastern edge of the Ghats[7]. Sampling areas in KMTR are located on the eastern slope of the hill range, and they fall under the rain shadow region for the south-west monsoon. The annual rainfall here is about 2000 mm. The temperature ranges between 4°C and 32°C during the year. The sampling sites were located at an altitudinal gradient from 740 m to 1260 m above mean sea level. The study was conducted between June 1996 and August 1997.

[‡]For correspondence. (e-mail: karthik@wii.gov.in)

In this article, we address the following:

1. What are the factors that control the diversity and distribution of amphibians in the three sites?
2. What is the species composition and structure of amphibian communities in the rainforest floor?
3. Did adaptive cluster sampling outperform random quadrat as a sampling method for forest floor amphibians?

Methods

We used four methods to sample amphibians: adaptive cluster sampling using quadrat searches, visual encounter surveys, audio surveys, and opportunistic records. In this paper, we primarily discuss results from an analysis of the quadrat data, information on overall species richness alone was pooled from all the methods employed during the study.

Quadrat sampling

An area of 0.5×2 km (1 sq km) was chosen on a drainage with the stream as the mid-point for intensive sampling in each of the three sites. Quadrats of 5×5 m were demarcated on the forest floor and searched thoroughly by two observers. Leaf-litter within the area was turned, rocks were lifted and searched underneath, shrubs were shaken and gleaned, fallen logs were ripped apart, loose bark of trees was peeled and examined, tree holes and cavities on the floor were prodded and searched for the presence of amphibians. This method was used to sample target groups such as the forest floor dwelling amphibians and hence might have excluded canopy dwelling, subterranean and aquatic species.

Adaptive cluster sampling

We used adaptive cluster sampling[10,11] to increase the detection of amphibians. The fundamental units of this sampling are 'primary quadrats', which are independent of each other, constituting data points. If an animal was detected in one of these quadrats (primary quadrats), additional quadrats of the same dimensions (called secondary quadrats) were searched on four sides of the primary quadrat. The riparian zone along the hill streams were thus sampled, where most of the amphibian species were found. If any of these quadrats had animals, further quadrats were laid around them until the quadrats with animals were bound or surrounded by quadrats without animals. The quadrats with the animals then become a cluster. If the primary quadrat did not have any animals, sampling was carried out in the next primary quadrat. Subsequent primary quadrats were laid 20 m away from the nearest edge quadrat of the previous cluster. One side of primary quadrat was always at the stream edge. It is for the first time ever that this method has been employed for sampling terrestrial vertebrates.

Initially, during the north-east monsoon in 1996, the forest floor was sampled using quadrats without resorting to adaptive cluster sampling. During this season 403 quadrats were laid at random distances starting from the stream edge and moving away at right angles from the stream up to 250 m. Quadrats were not placed on water. Adaptive cluster sampling covered only the summer and south-west monsoon seasons of 1997. A total of 102 primary quadrats and 427 secondary quadrats were sampled using adaptive cluster sampling.

Habitat parameters recorded within a quadrat were: (1) Physiographic variables: elevation, slope, soil moisture, soil temperature, and soil pH. (2) Vegetation variables: canopy cover, root cover, shrub density, herb density, fallen logs, leaf-litter cover. (3) Other microhabitat features: rocks, leaf-litter depth, snags, trees with buttresses, tree holes and lianas were enumerated. The selection of microhabitat parameters was subjective and hence biased. However, the use of similar measures has been reported in the literature[12].

Analyses

For the purpose of analyses, we define the term cluster to be an aggregation of adjacent quadrats with amphibian detections. The following parameters were estimated from the data:

1. The number of primary quadrats with animals: This is an indicator of the abundance of clusters.
2. Cluster size: The number of quadrats in a cluster, as an indicator of the area occupied by a cluster of animals.
3. Species richness in a cluster: Indicator of species richness in the area, since clusters were repeatable units in an area.
4. Density in a cluster: Indicator of the abundance of animals in a cluster, controlling for area of the cluster, expressed as the number of animals/quadrat in a cluster.
5. Density in the area: Estimate of the population density in the area. This is the mean of the densities by random quadrats and adaptive cluster sampling. This estimate includes random quadrats and primary quadrats without animals (density of zero). In the case of adaptive cluster sampling boundary quadrats (secondary quadrats without detection) were not included for calculating density.
6. Species composition: The percentage of animals of a particular taxon out of the total number of animals recorded from the quadrats.

Species identification

We collected amphibians during sampling and preserved some for future verification in 10% formalin. We identified some species in the field and preserved specimens by examining them using published keys for bufonids and ranids[13,14], microhylids[15], rhacophorids[16] and caecilians[17].

Results

Distribution pattern

Data obtained by constrained random placement of quadrats during the north-east monsoon reveal that mean abundance of amphibians was extremely low per quadrat (mean = 0.37, variance = 0.55, $N = 403$). There were on an average only 148 amphibians in one hectare of the forest floor. If a successful quadrat is termed as one that resulted in the detection of at least one amphibian, then percentage success in quadrats declined from 85% at the stream edge to 35% at 20 m away from water during the north-east monsoon. The decline in success continued until it was only 2% at 175 m away from water. Out of 96 quadrats that were searched from water edge up to 25 m, 43% of them had amphibians. Mean density per quadrat in this zone was 0.79 (variance = 1.28, $N = 96$). Rock cover, litter cover, litter depth, and distance of the quadrat from water, differentiated quadrats with amphibians from those that did not have amphibians (Discriminant Function Analysis, Wilk's $l = 0.889$, $c^2 = 46.15$, $df = 13$, $P < 0.001$).

The data from adaptive cluster sampling revealed that amphibians were distributed in clusters in the rainforest floor. Only 50% of the primary quadrats ($N = 102$) had amphibians. The cluster size varied considerably from 1 to 14 quadrats, with a mean of 4.02 and median of 3.00. Only 32% of the clusters had a cluster size of one quadrat, while 53% had three or more quadrats (Figure 1). Thus amphibians occur as fairly large clusters with a mean area of about 100 m^2 and a median area of 75 m^2. The number of amphibians in a cluster varied from one to 43, with a mean of 7.58 animals and a median of 5.00. As expected this was highly correlated with the number of quadrats in the cluster ($r_S = 0.925$, $N = 48$, $P < 0.001$).

The density of amphibians in a cluster varied from 1 to 4 animals per quadrat, with a mean of 1.62 and a median of 1.50. Thus, amphibians on an average occur as clusters of about 7 animals occupying an area of about 100 m^2. The mean density for all species together was 0.85 animals per quadrat (variance = 0.012), or 349 animals/ha.

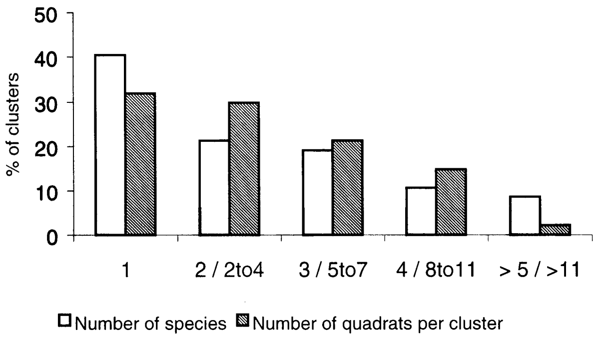

Figure 1. Frequency distribution of the number of quadrats and amphibian species in clusters during 1997 dry and south-west monsoon seasons in KMTR.

There was, however, considerable variation both in the area of the cluster as well as the number of animals in the cluster. Amphibians occurred as multi-species assemblages in the clusters. Only 40% of the clusters had one species, 21% had two species and 39% had more than two species with a maximum of nine species (Figure 1). The species richness in a cluster increased with the area of the cluster, but reached an asymptote at about four quadrats. The number of species also increased with the number of amphibians in a cluster, as expected ($r_S = 0.587$, $N = 48$, one-tailed $P < 0.05$).

Spatio-temporal variation

There was a considerable variation in many of the parameters among the three sites and to a lesser extent among seasons. Number of clusters were not different among sites (Chi-square test, $c^2 = 2.03$, $df = 2$, $P = 0.45$) when seasons were pooled, and between seasons (Chi-square test, $c^2 = 0.323$, $df = 1$, $P = 0.65$) when sites were pooled. Cluster size did not have any difference between sites in summer (Kruskal–Wallis test, $c^2 = 3.07$, $df = 2$, $P = 0.215$), and south-west monsoon (Kruskal–Wallis test, $c^2 = 1.466$, $df = 2$, $P = 0.48$), or together (Kruskal–Wallis test, $c^2 = 3.08$, $df = 2$, $P = 0.215$). Cluster size was larger in south-west monsoon in all the sites (Figure 2 *a*). Even though the seasonal differences were not significant for each site, when sites were pooled, cluster size in south-west monsoon (mean = 5.23, S.E. ± 0.76) was significantly different from that in summer (mean = 2.92, S.E. ± 0.52; Kruskal–Wallis test, $c^2 = 5.61$, $df = 1$, $P < 0.02$).

A total of 10 species were recorded from Kakachi, 10 from Kannikatti, and 6 from Sengaltheri. The difference between sites in mean species richness per cluster was not significant in summer (Kruskal–Wallis test, $c^2 = 0.53$, $df = 2$, $P = 0.76$), but significant in south-west monsoon (Kruskal–Wallis test, $c^2 = 13.96$, $df = 2$, $P < 0.001$, Figure 2 *b*). None of the clusters in Sengaltheri had more than two species, while 62.5% of the clusters in Kakachi had more than three species (up to a maximum of seven species), and 33.4% of clusters in Kannikatti had more than three species (up to a maximum of six species). Thus, Sengaltheri had far fewer species per cluster compared to the other two sites. When pooled across seasons, Kakachi had the highest number of species per cluster (mean = 3.12, S.E. ± 0.49), followed by Kannikatti (mean = 1.89, S.E. ± 0.33) and Sengaltheri (mean = 1.77, S.E. ± 0.2; Kruskal–Wallis test, $c^2 = 6.13$, $df = 2$, $P < 0.05$). Number of species in a cluster did not vary among seasons when sites were pooled (Kruskal–Wallis test,

$c^2 = 0.45$, $df = 1$, $P = 0.5$). Amphibian densities were not different among sites when seasons were pooled (Kruskal–Wallis test, $c^2 = 2.89$, $df = 2$, $P = 0.235$) or among seasons when sites were pooled (Kruskal–Wallis test, $c^2 = 0.046$, $df = 2$, $P = 0.83$, Figure 2 *c*).

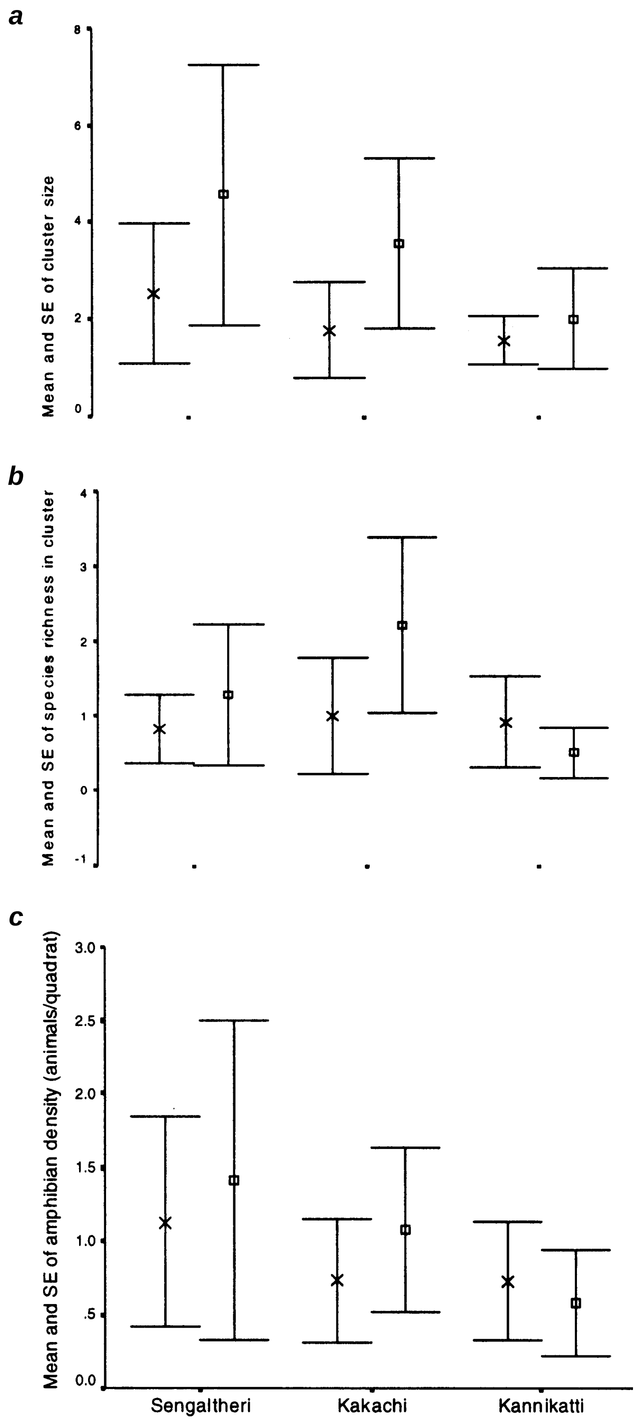

Figure 2. Variation in (***a***) cluster size, (***b***) number of species, (***c***) amphibian density in three sites during 1997 dry and south-west monsoon seasons in KMTR. × indicates mean values for summer; □ indicates mean values for south-west monsoon.

Species composition

Using adaptive cluster sampling, 225 amphibians belonging to 14 species were recorded. Estimation of species density was not possible since many of these occurred infrequently. Analysis is therefore based on genera, viz. *Bufo* (2 species), *Indirana* (3 species), *Micrixalus* (3 species), *Rana* (1 species: *Rana temporalis*), *Ramanella* (1 species: *Ramanella montana*) and *Philautus* (4 species). *Rana temporalis* was the most common taxonomic group with a density of 0.399 animals per quadrat, followed by *Micrixalus* (0.215 animals per quadrat). The densities of other groups were considerably lower, 0.097 for *Philautus*, 0.041 for *Indirana*, 0.031 for *Ramanella montana* and 0.014 for *Bufo*.

Density of some frog species in quadrats in which they occurred was highest in the case of *R. temporalis*. (mean = 2.14, S.E. ± 0.18), followed by *Micrixalus* (mean = 1.4, S.E. ± 0.09) and *Philautus* (mean = 1.09, S.E. ± 0.05). *R. temporalis* also formed large clusters with a maximum of up to 41 animals; *Micrixalus* and *Philautus* formed relatively smaller clusters (maximum of 18 and 7 animals respectively), and other taxa even smaller (up to 4 animals only).

The community of amphibians identified by the multi-species clusters had 43% *Rana*, 30% *Micrixalus*, 18% *Philautus*, 7% *Indirana*, 1% *Ramanella* and 1% *Bufo*. *R. temporalis* was the dominant group forming 49% ($N = 84$) in summer and 39% ($N = 141$) in south-west monsoon, *Micrixalus* was the next dominant genus in both the seasons (27% & 31% respectively) and *Indirana* the third (17% & 19% respectively). After pooling data for seasons and sites, the dominant members of the amphibian community were *R. temporalis* 43% and *M. fuscus* 21%. *R. temporalis* clearly dominated (84%) the amphibian community in Sengaltheri. Both *Micrixalus* (45%) and

A pair of *Micrixalus fuscus*, a frog typical of the rainforest, found in the leaf litter (Photo: S. U. Saravanakumar).

Philautus (32%) were dominant in Kakachi. In Kannikatti, *R. temporalis* (48%) and *Philautus* (25%) were the dominant taxa (Figure 3).

Micrixalus fuscus was the most common representative of the genus and was common in all three sites. *M. saxicola* occurred only in Kakachi and Kannikatti. A yet to be identified *Micrixalus* species was found only in Kakachi. *Indirana brachytarsus* was the dominant species of the genus in all the three sites. Since *I. beddomi* and *I. brachytarsus* had striking morphological similarities and *I. beddomi* occurred infrequently, it was difficult to quantify its abundance in some of the sites. However, it occurred more frequently than *I. diplosticta*. In the genus *Philautus*, *P. variabilis* was the most common in all the three sites. *P. charius* was found only in Kakachi, the remaining two species were shared between Kakachi and Kannikatti.

Species richness

We have recorded only 32 species (Appendix 1) from the Ashambu hills despite intensive sampling during 1996–1997. The present study has produced at least seven new records for the region and even more for the reserve (Table 1). Arboreal amphibians and caecilians contribute most to the new records for the region. A large proportion (52%) of the arboreal amphibians inhabiting the rainforests of the Western Ghats was represented in KMTR. In contrast, only 26% of the stream and forest floor amphibians and 22% of the caecilians of the Western Ghats rainforests were represented in KMTR. Even though nearly 120 species of amphibians have been reported to occur in the Western Ghats, only 32 species were recorded from the rainforests of KMTR.

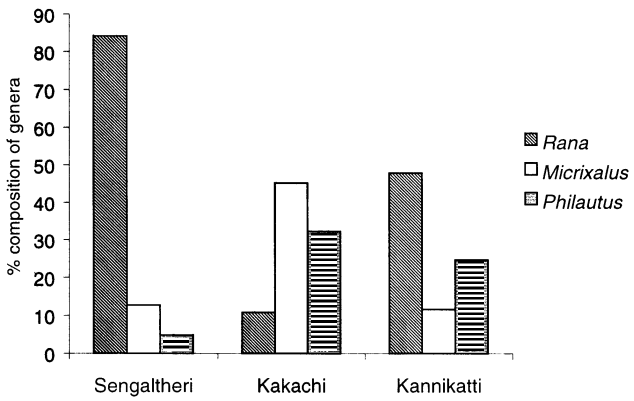

Figure 3. Percentage composition of three genera of amphibians in three sites during 1997 dry and south-west monsoon seasons in KMTR.

Discussion

Amphibian distribution

Adaptive cluster sampling was a better method for sampling rainforest floor amphibians, compared to the conventionally used quadrat sampling in this study. It provided a better understanding of the distribution of amphibians in the rainforest floor in terms of the abundance of clusters, mixed species assemblages, and their composition. Moreover, clusters seem to be better sampling units (than quadrats) for examining the relationship between amphibian distribution and micro- and macrohabitat parameters. This sampling protocol provided an unbiased estimator of mean density and the variance associated with it. We also feel that the data from this sampling have the potential to generate several testable hypotheses on the structure of forest floor amphibian communities. The only drawback of the method is the drastic reduction in sample size for the same sampling effort, since the parameters are estimated as cluster means rather than per quadrat. This becomes even more so as cluster size increases. Our data from random quadrats suggest that the rainforest floor amphibians irrespective of species aggregate close to water. Similar patterns have been observed with amphibians through mark-recapture study in Malaysia[18]. Adaptive clusters worked in the riparian strata (stream edge to 20 m away from water) and these data only represent the amphibian communities along the rainforest streams.

The estimate of density using adaptive sampling was almost three times more than that obtained using simple random quadrat sampling. The estimate of density using adaptive cluster sampling could be inflated since it represents only the riparian zone, where the amphibians were more in number. The density from random quadrats estimated for the riparian zone was less than that estimated using adaptive cluster sampling. More importantly, the variance associated with the mean was far less (100 times)

Table 1. Comparison of amphibian species richness recorded in KMTR and the entire Western Ghats

Region	Total species	Rainforest amphibians: Total	Stream and forest floor	Arboreal	Caecilians
Western Ghats	ca. 120	ca. 100	62	25	14
Kalakad WLS[21]	29	18	13	5	0
KMTR (this study)	–	32	16	13	3

for adaptively sampled data in comparison to that from random quadrat. This could have come about because of one or more of the following reasons. (1) Adaptive cluster sampling resulted in over-estimation of the density. (2) Simple quadrat sampling produced an under-estimate. (3) The amphibians showed large seasonal fluctuation in abundance, thereby influencing both the mean and variance. (4) Adaptive cluster sampling provided a truly better estimate of density than that by random quadrats. The results presented here provide no evidence for marked seasonal variation in amphibian abundance between dry and south-west monsoon. The design of the adaptive cluster sampling and calculation of the unbiased estimator of density precludes the possibility of overestimation[11]. Therefore, the difference observed could have resulted from greater efficiency of adaptive cluster sampling over random quadrat sampling, or because of large variance in data from random sampling the mean might be an under-estimate or, both these explanations could have operated together.

Spatio-temporal variation

Number of clusters and cluster size had contrasting differences with seasons and sites. The properties of these 'clusters of amphibian distribution' have not been explored in detail. Large cluster size in south-west monsoon might have resulted because of more number of species per cluster during this season than in summer. Kakachi has the most number of species per cluster and seemingly a more even community than the other two sites. Sengaltheri, which had the least number of species per cluster, was largely dominated by one species. This site also had the highest density of amphibians in both the seasons and greatest variance for all the estimates. We feel that this pattern could have been largely shaped by the dominant species *R. temporalis*. In KMTR, the forest floor amphibian community varied considerably among these sites. Local factors seem to largely influence the forest floor amphibian community.

Species composition

The dominance of the amphibian community by a single taxon (*Rana*) was higher in Sengaltheri than in Kannikatti. *Rana* and *Micrixalus* were the most dominant taxa in these two sites, while it was *Micrixalus* and *Philautus* in Kakachi. In contrast to Sengaltheri, amphibian communities in Kakachi and Kannikatti were less dominated by a single taxon (Figure 3). We speculate that low equitability in Sengaltheri is because of one or both of the following reasons. (1) This area might be influenced by 'natural disturbance' through flooding and unpredictable rainfall (pers. obs.). Findings from an earlier study[19] support such reasoning where, contrary to popular belief about 'constancy' in the rainforest, the habitat was prone to disturbance through unpredictable events that resulted in low evenness of the forest floor amphibian community. (2) This area might be influenced by adjoining drier forest since this site lies in the vegetation transition zone.

Species richness

The black narrow-mouthed frog, *Melanobatrachus indicus* was rediscovered in KMTR, nearly 120 years after its first description[20]. The inventory of species in KMTR is incomplete and the taxonomy of some genera such as the *Philautus* has been problematic. The Kalakad Wildlife Sanctuary, which now forms a subset of KMTR, was reported to be richest in amphibian species among the protected areas in the southern Western Ghats[21]. It is interesting to note that long-term studies in different hill ranges have all reported 30–40 species in a hill range, e.g. Nilgiri hills[22], Brahmagiri hills (Krishnamoorthy, pers. commun.), Anamalai hills (K. Vasudevan *et al*., unpublished data), and Ashambu hills (this study). Our studies[23] show that there is turnover and abundance changes even on local scales, from one drainage to another within a hill range. The turnover is higher between drainages separated by greater distances, such as those between two hill ranges (between Ashambu hills and Anamalai hills). It is becoming increasingly clear that the high species richness in amphibians in the Western Ghats is due to the high beta and gamma diversity. Since the Western Ghats is a linear habitat it is almost impossible to control for distance, while examining differences between drainages. Amphibian distribution in the forest floor was found to be largely restricted to the forest adjoining streams. The mountains flanking the valleys may restrict the dispersal of several species of forest floor amphibians across drainages, and thus promote speciation. We speculate that drainage greatly influences amphibian diversity in the Western Ghats. This further supports the view that geological history of the region has largely shaped the diversity of amphibians in the Western Ghats. The influence of altitude and latitude on species diversity observed in different groups[8,24] however, might still hold good at a regional scale.

Appendix 1. List of amphibians recorded from Kalakad–Mundanthurai Tiger between May 1996 and August 1997 (includes unidentified species).

I. Family: Ichthyophidae
Ichthyophis species 1
Ichthyophis species 2

II. Family: Uraeothyphlidae
Uraeotyphlus malabaricus

III. Family: Bufonidae
Bufo melanostictus
B. beddomi

B. microtympanum
B. species

IV. Family: Microhylidae
Melanobatrachus indicus
Ramanella montana

V. Family: Rhacophoridae
Philautus variabilis
P. pulcherrimus
P. charius
P. glandulosus
P. species
Polypedates maculatus
Rhacophorus calcadensis

VI. Family: Ranidae
Euphlyctis cyanophlyctis
Indirana beddomi
I. brachytarsus
I. leptodactyla
I. diplostictus
Limnonectes keralensis
Micrixalus fuscus
M. saxicola
M. species
Nyctibatrachus aliceae
N. major
N. vasanthi
N. beddomi
Rana aurantiaca
R. curtipes
R. temporalis

1. Jayaram, K. C., in *Ecology and Biogeography in India* (ed. Mani, M. S.), Dr W. Junk, The Hague, 1974, p. 535.
2. Inger, R. F. and Dutta, S. K., *J. Bombay Nat. Hist. Soc.*, 1986, **83** (suppl.), 135–146.
3. Kumar, A., Walker, S. and Molur, S., *Prioritisation of Endangered Species*, Report submitted to WWF-India, 1998.
4. Dutta, S. K., *Amphibians of India and Sri Lanka* (*Checklist and Bibliography*), Odyssey Publishing House, Orissa, 1997, p. 342.
5. Inger, R. F., *Herpetologica*, 1996, **52**, 241–246.
6. Vasudevan, K. and Dutta, S. K., *Hamadryad*, 2000, **25**, 21–28.
7. Nair, S. C., *The Southern Western Ghats: A Biodiversity Conservation Plan*, INTACH, New Delhi, 1991, p. 92.
8. Daniels, R. J. R., *J. Biogeog.*, 1992, **19**, 521–529.
9. Ramesh, B. R., Menon, S. and Bawa, K. S., *Ambio*, 1997, **26**, 529–536.
10. Thompson, S. K., *Biometrics*, 1991, **47**, 1103–1115.
11. Thompson, S. K., Ramsey, F. L. and Seber, G. A. F., *Biometrics*, 1992, **48,** 1195–1199.
12. Inger, R. F., in *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians* (eds Heyer, W. R., Donnelly, M. A., McDiarmid, R. W., Hayek, L. C. and Foster, M. S.), Smithsonian Institution USA, 1994, pp. 60–61.
13. Boulenger, G. A., *The Fauna of British India, including Ceylon and Burma, Reptilia and Batrachia*, Taylor and Francis, 1890, xviii + 541 pp.
14. Boulenger, G. A., *Rec. Indian Mus. Calcutta*, 1920, pp. 1–226.
15. Parker, H. W., *A Monograph of the Frogs of the Family Microhylidae*, British Museum, London, 1934, vii + 208 pp.
16. Ahl, E., *Anura III, Polypedatidae*, Das Tierreich, Walter de Guyter, Berlin and Leipzig, 1931, xiv + 477 pp.
17. Taylor, E. H., *J. Bombay. Nat. Hist. Soc.*, 1961, **58**, 355–365.
18. Inger, R. F., *J. Appl. Anim. Ecol.*, 1969, **38**, 123–148.
19. Loyd, M., Inger, R. F. and King, W. F., *Am. Nat.*, 1968, **102**, 497–515.
20. Vasudevan, K., *J. Bombay Nat. Hist. Soc.*, 1997, **94**, 170–171.
21. Ravichandran, M. S., *Cobra*, 1996, **23**, 15–31.
22. Easa, P. S., KFRI Res. Rep., No. 148, 1998.
23. Vasudevan, K., Ajith Kumar and Ravi Chellam, Paper presented at the National Seminar on Wildlife Conservation and Management at Wildlife Institute of India, Dehradun, 11 to 13 August, 1998.
24. Pascal, J. P., *Wet Evergreen Forests of the Western Ghats of India: Ecology, Structure, Floristic Composition and Succession*, Institut Francais de Pondichery, Trav. Sec. Sci. Tech., 1988, Tome **20** bis 345 p.

ACKNOWLEDGEMENTS. We thank the U.S. Fish and Wildlife Service and the Wildlife Institute of India for funds and logistic support and B. C. Choudhury for his suggestions and support for the project. Barry Noon provided us valuable inputs on sampling design and analyses of data at the right time. The Tamil Nadu Forest Department granted research permission and facilitated research in KMTR. Sushil Dutta helped with identification of specimens. Our staff, Ganesh, Arumugam, Rajamani and Mariappan, provided much assistance during fieldwork. Project colleagues Divya Mudappa and N. M. Ishwar provided valuable inputs through discussions.