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Amphibian diversity and distribution in Tamhini, northern Western Ghats, India

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Monitoring and mapping of biological resources is a major concern from the conservation perspective, since the depletion of biodiversity is an irreversible change. In this study, we have monitored diversity and distribution of amphibian fauna of Tamhini, northern Western Ghats (18°27′N lat and 73°25′E long), using two methods – habitat ad hoc searches to produce checklists and transects to quantify seasonal change in diversity. First, we surveyed various localities from the study area (25 km^2) using ad hoc search method and prepared a checklist of species from different habitats. The species were categorized as very common, common, occasional, rare and absent. Secondly, transect sampling surveys were conducted and the number of individuals of each species was noted. Ad hoc searches depicted different distribution patterns and habitat specificity, while transects revealed seasonal changes in diversity and occurrence of amphibians.

ECOSYSTEM functioning is dictated to a large extent by diversity and the community structure that results from factors such as richness and evenness of diversity[1]. Thus, recent studies in biology focus more on the quantitative aspects of biodiversity that can be used to understand fluctuations in ecosystem functioning and help in prioritization of areas for conservation[2].

The Western Ghats of India, considered as one of the 25 biodiversity hotspots in the world[2], is rich in amphibian fauna. Among the 224 species of amphibians known from India, 117 (60%) occur in the Western Ghats, 89 being endemic to this region[3]. However, biodiversity of the Western Ghats is under threat due to deforestation[4]. Thus, to assess and measure the biological diversity in Western Ghats, so as to design and implement effective conservation strategies, the Western Ghats Biodiversity Network (WGBN) organized a programme of sampling species-level diversity in number of taxa in 25 different localities distributed over the length of Western Ghats[5]. Current study is a part of the programme and was conducted in one of the 25 localities.

The decline in amphibian population is a major concern throughout the world[6,7]. The causes of catastrophic decline vary and include diseases[8], increased exposure to UV-B radiation[9], impact of urbanization[10,11], habitat destruction[11–14], pollution[14] and specimen hunting[14]. As amphibian inhabit both terrestrial and aquatic habitats, a change in either or both the ecosystems can lead to a catastrophic effect in amphibian diversity. Thus, the widespread approach of surveys and

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preparation of checklists should be combined with quantitative estimates so as to devise potential conservation measures[12].

We conducted an extensive amphibian survey of a small area of 25 km^2, situated in the northern Western Ghats of India, from June 1997 to November 2000. Tamhini (18°27′N lat and 73°25′E long) is a small village situated in the northern part of the Western Ghats (Figure 1). Its population is around 500 to 700. The average altitude of the village and its surrounding area is 600 m asl, while the surrounding hilltops range from 850 to 1050 m asl. The study area includes four other small villages, namely Nivewadi, Sarole, Dhangarwadi and Dongarwadi. A part of the study area, especially around the villages is a private farmland. Some mountain slopes bear Reserved Forests under the control of the Forest Department. The major habitat is scrub and grasslands, both at the foothills and mountaintops, followed by paddy fields near human habitation. The hilly regions show little primary evergreen forest restricted to sacred grooves and comparatively more secondary evergreen and moist deciduous forests.

In the present study, we analysed the amphibian diversity using two different methods – the ad hoc searches to prepare checklists and transects to quantify seasonal changes in diversity. In the ad hoc search method, we sampled the amphibian diversity in different sites (Figure 1) by random surveys. A checklist of species along with their relative abundance in terms of broad occurrence patterns was prepared. These surveys were conducted from June 1997 to November 2000, during late evenings, when frog calls were distinctly heard and frogs were observed frequently. A few surveys were also conducted during the daytime. Various sites representing different landscape elements (Figure 1, Table 1) from the study area were scanned for their amphibian

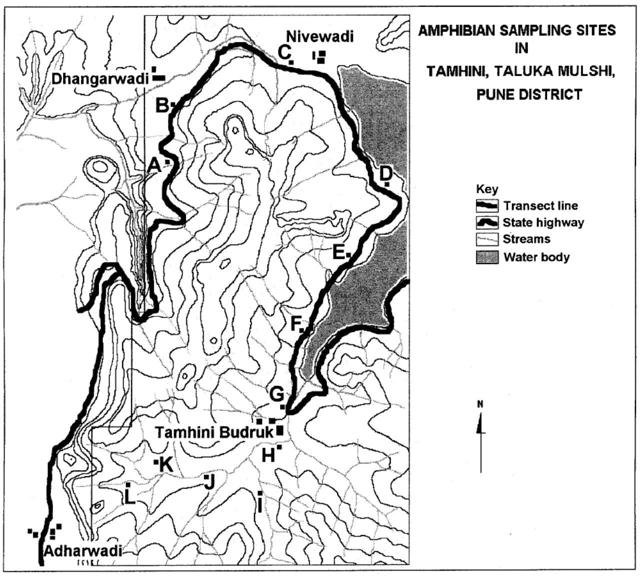

Figure 1. Study area. The total 25 km^2 area is bound by grey line. Locations A to L correspond to sites in Tables 1 and 2.

diversity and a checklist of species was prepared and the relative abundance of species in terms of very common (VC), common (C), occasional (O), rare (R) and not recorded (N) was tabulated (Table 2). Collection was done along the streams, in paddy fields and forest patches, by searching in the litter, on the trees in bark and leaves, in water ditches and rock crevices near water-bodies or in streams. Frogs were collected in 'Pearlpet' jars by hand or using small nets. The exact location of collection of different frog species was noted. Identification of frogs was done using available literature[15–20], and confirmed by taxonomists. The taxonomic status, checklist and relevant data have been published earlier[11,12].

In transect sampling method, we selected a band transect and calculated per cent species abundance from the actual number of individuals encountered during transect sampling. These transect sampling surveys were conducted from May to November 2000. The transect was selected such that all major breeding habitats were on the roadside. The method relies on the fact that frogs respond to a mating call in the breeding season, and migrate in the direction of the calls. This leads to local and time-specific migration of frogs towards the breeding habitats such as paddy fields, temporary rainwater pools, water tanks, etc. A road of 10 km length was considered for the frog transect, with a width of approximately 4 to 5 m. The transect was repeated every month from May to November 2000, during the late evening from 7 to 9 pm. All individuals encountered only on the transect line were identified to the species level and the number of individuals was recorded.

The data gathered from transects were used to estimate the species richness of the study area by fitting a Michaelis–Menten equation, $S = S_{max}N/(K_m + N)$ to species individual data[21]. Here, S is the number of species, N the number of individuals, S_{max} the maximum number of species that could be present and K_m the Michaelis–Menten constant. The data were also used to find abundance of species during different months (Table 3) and to calculate richness, diversity and evenness indices[22]. Margalef's species richness index was calculated using the equation: $R = (S - 1)/\ln N$, where S is the number of species and N the total number of individuals. The Shannon index of diversity was calculated using the equation: $H' = -\Sigma p_i\ (\ln p_i)$, where $p_i = n_i/N$ and n_i is the number of individuals of ith species and $N = \Sigma n_i$. The evenness index was calculated by the equation: $E = H'/\ln S$. Similarity between the species composition for different months of transect sampling was determined using Bray–Curtis similarity index[22].

As a result of the extensive survey of the study area since 1997 to 2000, we documented the presence of 23 species of frogs belonging to 8 genera and 4 families (Table 2). Family Ranidae was the most dominant with 61% of the total anuran species. Rhacophoridae was the next, contributing 26%, while Microhylidae and Bufonidae contributed to 9% and 4% respectively. Though Bufonidae contributes only 4% of the total anuran species, its abundance was high.

Table 1. Distribution of frog species, belonging to four families, in different collection sites

Collection site*	Habitat	Number of species of the given family**			
		Bufonidae (1)	Microhylidae (2)	Ranidae (14)	Rhacophorideae (6)
A	Evergreen forest, seasonal streams and rock crevices	0	0	7	6
B	Paddy fields, forest margin with grasslands	1	0	8	3
C	Paddy fields	1	0	9	0
D	Roadside rainwater pool surrounded by secondary forest and sacred groove	1	1	8	2
E	Roadside rainwater pool surrounded by scrubland	1	1	9	1
F	Paddy fields and slow streams	1	1	8	1
G	Human habitation and paddy fields	1	0	8	1
H	Human habitation, paddy fields and major stream	1	1	8	1
I	Major stream with reserve forest and shift cultivation on sides	1	0	9	2
J	Semi-perennial deep water-body within stream	1	0	8	2
K	Bamboo thickets and scrubland	1	0	7	3
L	Fast-running stream, small waterfall and rock crevices	1	0	8	2

*Collection sites according to Figure 1.
**Number in parentheses indicates total number of species of the family found in the study area.

Table 2. Frog species and their relative abundance in different collection sites in the study area

Family	Frog species	Collection site*											
		A	B	C	D	E	F	G	H	I	J	K	L
Bufonidae	*Bufo melanostictus* Schneider	N	O	C	C	C	C	VC	VC	C	C	C	O
Microhylidae	*Microhyla ornata* (Dumeril and Bibron)	N	N	N	C	N	N	N	N	N	N	N	N
	Ramanella montana (Jerdon)	N	N	N	N	O	O	N	O	N	N	N	N
Ranidae	*Euphlyctis cyanophlyctis* Schneider	N	VC	VC	C	O	O	VC	C	C	VC	N	O
	Fejervarya cf. Keralensis Dubois	N	C	C	VC	VC	VC	C	C	VC	O	O	N
	F. limnocharis Gravenhorst	N	N	N	R	R	C	C	O	O	R	C	C
	F. nilagirica Jerdon	N	N	R	N	N	N	N	N	N	N	N	N
	F. rufescens (Jerdon)	N	N	N	N	O	C	VC	O	N	N	N	O
	F. syhadrensis Annandale	N	O	C	VC	VC	VC	VC	C	VC	C	C	C
	Hoplobatrachus tigerinus Daudin	C	C	VC	VC	C	VC	VC	VC	C	VC	C	C
	Indirana beddomei (Gunther)	C	C	C	N	N	N	N	N	C	C	C	C
	I. leithii (Bouleger)	O	N	N	N	N	N	N	N	N	O	N	N
	I. phrynoderma (Boulenger)	R	N	N	N	N	N	N	N	N	N	N	N
	Nyctibatrachus major Boulenger	VC	O	N	N	N	N	N	N	C	N	N	N
	Rana malabarica Tschudi	O	O	C	C	VC	VC	VC	C	O	R	R	R
	Sphaerotheca breviceps (Schneider)	N	N	C	C	O	O	N	N	N	N	N	N
	S. dobsonii (Boulenger)	O	C	C	C	C	N	O	O	N	N	O	O
Rhacophoridae	*Philautus bombayensis* (Annandale)	VC	VC	N	O	O	O	N	N	O	R	C	C
	Philautus leucorhinus (Lichtenstein & Martens)	R	N	N	N	N	N	N	N	N	N	N	N
	Philautus sp. (Closer to *glandulosus*)	O	N	N	N	N	N	N	N	N	N	N	N
	Philautus sp. (Closer to *bombayensis*)	O	N	N	N	N	N	N	N	N	N	N	N
	Polypedates maculatus (Gray)	C	VC	N	C	N	N	C	C	C	R	C	C
	Polypedates. sp. (different from *maculatus*)	R	R	N	N	N	N	N	N	N	N	R	N

*Collection according to Figure 1.
VC, Very common; C, Common; O, Occasional; R, Rare; N, Not recorded.

The listed frogs include bush frogs, tree frogs, torrent frogs, fossorial frogs, aquatic frogs and frogs of semi-arid areas. From the total area that we scanned, some frog species were distributed all over the study area, while others were found only in restricted patches (Table 2). *Bufo melanostictus* was found in all the collection sites except the evergreen forest patch near Plus Valley (site A, Table 1). It was a commonly encountered species and showed high relative abundance near human habitation (Table 2). Microhylid frog, *Microhyla ornata* showed restricted distribution and was found only in site D (Table 1) in a temporary water pool formed during the rainy season. The species showed repeated occurrence in the same area for three years during our study. Another microhylid, *Ramanella montana* was found in patchy distribution in sites E, F and H, its occurrence was occasional (Table 2). Family Ranidae contributed 14 species and was widespread in the study area. *Indirana phrynoderma* and *Nyctibatrachus major* showed restricted distribution confined to the evergreen forest patches (Tables 1 and 2). *Fejervarya nilagirica* was found rarely and only two specimens were collected and preserved. *Fejervarya rufescens* and *Sphaerotheca dobsonii* showed patchy distribution, while *Fejervarya syhadrensis*, *F. cf. keralensis*, *Hoplobatrachus tigerinus*, *Indirana beddomei*, *Euphlyctis cyanophlyctis* and *Rana malabarica* showed widespread occurrence and were relatively more common than the other species. Tree frogs belonging to the family Rhacophoridae were mainly found in evergreen forest patch (site A). However, common species *Philautus bombayensis* and *Polypedates maculatus* showed patchy distribution even in other locations in the study area.

Out of the total 23 species encountered in the ad hoc search, 15 species of anurans were found in transects. This number is almost 65% of the total anuran species found in this region. Out of eight species that were never encountered in transects, six were rarely found (Table 2). Since our transect method was carried out for only one year, the probability of encountering them was very low. A species accumulation curve (Figure 2) shows the best-fit curve ($r = 0.9897$, $P < 0.001$) with $S_{\max}$ value of 17 at k_m value of 37.6.

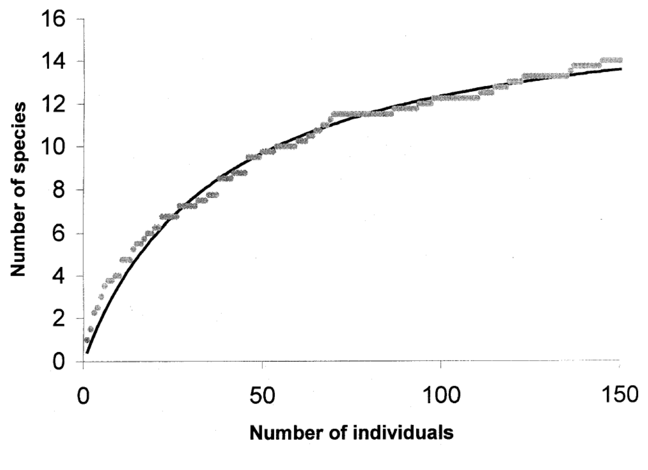

Figure 2. Species curve of frogs of Tamhini; $S_{\max} = 17$ at $K_m = 37.6$. Black solid line indicates theoretical curve (using Michaelis–Menten equation) and grey dots indicate actual data.

The per cent abundance of various anuran species during different months is given in Table 3. The transect recorded species from different habitats and included arid scrubland species like *B. melanostictus*; paddy field species like *R. malabarica*, *F. syhadrensis*, etc.; aquatic species like *E. cyanophlyctis*; subterranean species like *M. ornata, R. montana*, *Sphaerotheca breviceps*, etc.; and occasionally arboreal species like *Polypedates maculatus*. The most abundant species was *F. cf. keralensis* followed by *R. malabarica* and *B. melanostictus* (Table 3). The seasonal change in the richness, diversity and evenness of amphibians in the transect data is given in Figure 3, while the dendrogram of month-wise similarity in amphibian species composition is given in Figure 4.

Our preliminary study depicts three major patterns of amphibian distribution in our study area. Out of total 23 species, eight species were restricted to a maximum of three localities, while another five species showed patchy distribution in three to seven localities within the study area. The remaining ten species showed more or less continuous distribution, though their abundance levels varied from locality to locality (Table 2). Since, many frog species are particular to their habitats (Tables 2 and 3), they will be under threat if such habitats are lost. One such example encountered recently is the loss of *M. ornata* from site D (Table 2). The typical habitat, where a loud chorus of large population of *M. ornata* could be heard, has perished due to the road widening for a state highway.

Patchy distribution is one of the most important factors that affect the distribution of frogs[3]. Tree frogs, especially of the genus *Philautus*, show patchy distribution due to their specificity of habitat (Table 2). The slash and burn technique of shift cultivation involves cutting of a forest patch for agricultural practices, which destroy the habitat of *Philautus*. This and other human activities involving cutting of trees will contribute to decline of such arboreal species of anurans.

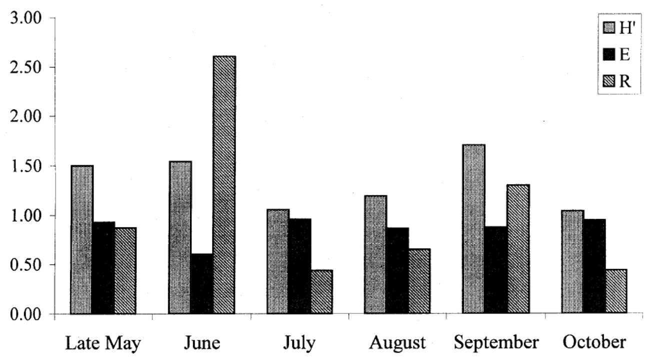

Figure 3. Change in Shannon diversity index (H'), evenness (E) and richness (R) of amphibians from May to October 2000.

Table 3. Per cent abundance of species recorded during transect sampling, in various seasons

	Percentage abundance (n_i*100/N)						
Species	Late May	June	July	August	September	October	Total
B. melanostictus	30.77	17.57	40	0	10	25	16.76
E. cyanophlyctis	0	0.84	0	0	11.43	0	2.89
I. beddomei	15.39	0	0	0	17.14	25	4.34
F. limnocharis	0	0.42	0	0	0	0	0.29
F. cf. keralensis	30.77	39.75	20	40	40	50	39.02
F. rufescens	0	1.67	0	10	7.14	0	2.89
F. syhadrensis	15.39	2.09	0	0	4.29	0	2.89
H. tigerinus	0	1.67	0	40	10	0	4.34
N. major	0	0.42	0	0	0	0	0.29
R. malabarica	0	30.96	40	0	0	0	22.54
S. breviceps	0	1.26	0	0	0	0	0.87
S. dobsonii	0	0.42	0	0	0	0	0.29
Ramanella montana	0	1.26	0	0	0	0	0.87
P. bombayensis	0	0	0	10	0	0	0.29
P. maculates	7.69	1.67	0	0	0	0	1.45

*n_i, Number of individuals in *i*th species; N, Total number of species.

Many frogs were also observed dead on the road due to encounters with passing vehicles. These mainly involved gravid females of *R. malabarica*, which showed sluggish movement during the mating season. Young ones and sub-adults of different species died similarly. The intensity of the road-kill will increase drastically due to the new state highway, and will be a major cause for the decline in the populations.

Out of the four genera of anurans endemic to the Western Ghats, *Nyctibatrachus* is worst affected due to habitat destruction, fragmentation and modification[23]. The new state highway passes through the Plus Valley area (site A, Figure 1), where we have reported *N. major* in large numbers (Table 2). Increase in the disturbance and filling of rock crevices as a part of the highway construction activity, might affect the population of this species. Since new species of *Nyctibatrachus* are still found and described[24], loss of such endemic species may also contribute to loss of unexplored diversity.

Transect sampling revealed the diversity of frogs in the study area. However, the method did not account adequately for the arboreal frogs, which were heard but only seldom found in the transects. Other methods like pitfall method, bamboo traps, quadrate, stream transect, etc. are known to be reliable[25–27]. However, they are habitat-specific and cannot account for species inhabiting diverse habitats. This creates problems during comparisons while our method accounts for most, it not all, the habitats.

The reliability of this method in terms of proper population estimates is yet to be determined. However, the purpose of our study was not total population estimation. We were interested in knowing the diversity and distribution of amphibians in our study area for which this method is satisfactory.

The species accumulation curve (Figure 2) revealed that at least 17 species could be present in the study area. However, Paranjape and Gore[21] have stated that the species accumulation curves are influenced by the number of individuals encountered, and that if less than 1000 individuals are encountered, the number of species predicted from the curve could be 25% of the total species found in the area. This indicates that there could be more number of species present in the study area. Recent record of new genus *Minervarya*[28] as well as a new family Nasikabatrachidae[29] from southern Western Ghats indicates limitations in our knowledge of amphibian diversity even at family level. There is possibility of unreported and/or undescribed species in our study area[11,12]. Further studies on *F. cf keralensis*, *Philautus* sp. (close to *glandulosus*), *P.* sp. (closer to *bombayensis*) and *Polypedates* sp. from our study area are essential from this point of view.

The monthly per cent abundance (Table 3) and monthly changes in the richness, diversity and evenness indices (Figure 3) reveal a distinct abundance pattern of the anurans during the breeding season. *R. malabarica*, *F. limnocharis*, *N. major*, *S. breviceps*, *S. dobsonii* and *P. maculatus* were recorded only in late May and June transects (Table 3). This could be probably due to their early monsoon mating behaviour. *F. cf. keralensis*, however, showed constant occurrence throughout the breeding season. There were two peaks in species richness (Figure 3), one in June and the other in September. The peak in June was mainly because it is the onset of breeding season for almost all frog species in this area. The next two months, July and August, showed low richness and diversity, probably because newly laid eggs take around two months for complete morphogenesis. The peak of richness in September is mainly due to the emergence of juveniles at the end of the breeding season.

Interesting cladding pattern of similarity in species composition between months was observed in the dendrogram prepared from the transect (Figure 4). The pattern could be attributed mainly to the reproductive behaviour of the frogs and the climatic condition of the northern Western Ghats. The northern Western Ghats have longer dry periods (about

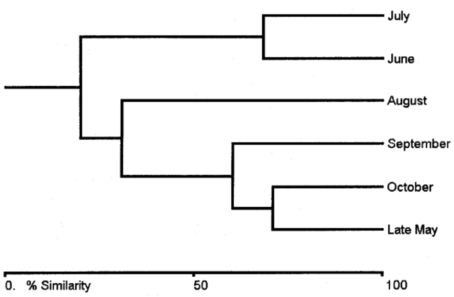

Figure 4. Dendrogram of month-wise similarity in amphibian species composition as depicted from transect data, based on the Bray–Curtis similarity index.

5 to 8 dry months), and the wettest months are June and July[3]. Hence, it is possible that in northern Western Ghats the frogs reproduce mainly during these months. This probably explains the relatively high similarity in the species composition in June and July (Figure 4). The relatively lower similarity in the species composition in August and September could be due to the decrease in mating frequency and the emergence of juveniles according to the duration of metamorphosis, which is species-specific. Thus, the juveniles of different species emerge in different periods, even though majority of mating is during June and July. Relatively high similarity in late May and October reflects the boundaries of onset and end of a breeding season.

In the context of threatened biota, including Western Ghats, it is becoming increasingly clear that systematic conservation planning should be implemented without delay[2,4,30]. Despite certain problems[14], it will be fruitful to prioritize certain high diversity areas from the Western Ghats for conservation. Recent case studies and reports[11,13,31] have discussed elaborately on conservation planning and its implementation. With increasing interest in the biodiversity conservation and setting priority areas, a site-wise comparison as well as repeated studies of the same area over a longer time period will help in determining the status of a site in terms of the diversity, and prioritizing sites for conservation.

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