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On the relationship between bird and woody plant species diversity in the Uttara Kannada district of south India

(biodiversity/tropical forest)

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ABSTRACT **Bird species richness is inversely related to woody plant species diversity and vertical stratification in the natural vegetation of Uttara Kannada, the district with the largest contiguous tract of humid tropical forest in peninsular India. This inverse relationship may be explained by the fact that although the peninsular Indian evergreen forests are rich in woody plant species when compared with the drier vegetation, they harbor an impoverished bird fauna due to their smaller overall extent and greater isolation. Much of this impoverishment is accounted for by the absence of many species of understory timaliids characteristic of the humid evergreen forests of the Eastern Himalayas and Southeast Asia. The plantations of Uttara Kannada largely derive their bird fauna from the drier vegetation and exhibit the commoner trend of a positive correlation between bird species richness and vertical stratification of the vegetation.**

Conservation of biodiversity has emerged as a key environmental concern of the day. Effective action in this context calls for an understanding of how biodiversity is distributed and maintained, in particular, within the species-rich tropical forest regions that are being rapidly depleted. We have limited information on these issues, much of it from investigations in a few localities on only a few taxa. It would be useful to know how far we can generalize from this limited data base and to answer questions, such as whether or not localities rich in bird species are also rich in plant species and whether humid tropical forests are richer in the diversity of all major taxa they share with drier tropical forests.

Our investigation has been motivated by such questions. It assesses diversity levels in two of the best studied taxa of organisms—namely birds and angiosperm woody plants across a gradient of natural and man-made vegetation types. This work focuses on Uttara Kannada, a district harboring the most extensive contiguous tract of humid tropical forest in south India.

MATERIALS AND METHODS

The district of Uttara Kannada (13°55′–15°32′N; 74°05′–75°05′E) marks the transition between the more seasonal northern and the less seasonal southern Western Ghats. Humid evergreen dipterocarp forests reach their northern limits of distribution in this district, as do several species of vertebrates, including birds such as *Muscicapa pallipes*, *Pycnonotus priocephalus*, and *Dendrocitta leucogastra*. The district has a narrow coastal strip flanked by hills rising to 600–850 m before merging with the peninsular Indian plateau at an altitude of 500 m to the east. The annual rainfall varies from >3000 mm along the coast to 5000 mm along the crest of the hills, declining to 1000 mm on the east (Fig. 1). Much

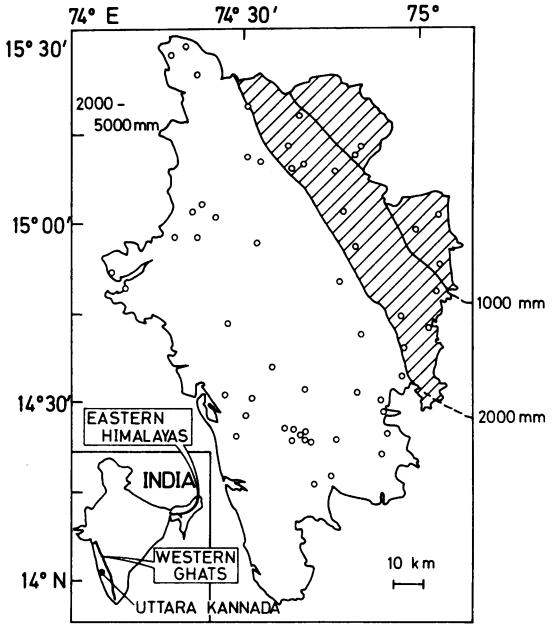

FIG. 1. Map of Uttara Kannada district showing major rainfall/vegetation zones and location of the 58 transects. ○, Transects; ▨, deciduous forest zone; □, evergreen/semideciduous forest zone.

of this rain is received during the monsoon months of June–October. Broad vegetation zones of the district correspond to this rainfall gradient. Evergreen forests with their secondary stages, which often include grass and thickets, dominate the coast and the western hill-slopes. Semideciduous and deciduous forests appear progressively eastward toward the plateau. Plantations, mostly monocultures of native as well as introduced tree species, including *Tectona grandis, Areca catechu, Eucalyptus, Casuarina equisetifolia, Acacia auriculiformis*, and *Anacardium occidentale*, form a patchwork throughout the forests of Uttara Kannada (1–3). These are extremely variable in age, structure, and composition (Table 1). Of these the betel nut (*A. catechu*) orchards are a traditional land-use system restricted to the evergreen forest zone and include many examples of mature plantations with a canopy in the range of 16–32 m. The *T. grandis, Acacia, Casuarina*, and *Eucalyptus* plantations have been raised in more recent times, and many of them represent young coppice growth.

Uttara Kannada with 60% of its 10,200 km^2 of land area covered by forests is not only the most forested district of the Western Ghats but also harbors the most diverse avifauna. A total of 403 species of birds have been reported from this district (4–7). Of these, 300 are land birds extensively using the forests. This bird fauna has changed but little over the past century in spite of many changes in land use (8).

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Table 1. Attributes of natural vegetation (n = 38) and man-made plantations (n = 20) of the Uttara Kannada district

Attribute	Vegetation type	Mean	SD	Minimum	Maximum	Statistical significance
Woody plant species, no.*	Plantations	11.89	5.99	1.00	23.00	S
	Natural vegetation	40.58	13.76	17.00	64.00	
Woody plant species diversity†	Plantations	3.70	2.08	1.00	7.90	S
	Natural vegetation	15.52	7.57	2.50	32.70	
Vertical stratification‡	Plantations	3.26	1.24	1.50	5.69	S
	Natural vegetation	4.34	0.85	2.25	5.59	
Canopy density§	Plantations	1.23	0.57	0.26	2.21	S
	Natural vegetation	1.74	0.62	0.62	2.85	
CV of canopy density¶	Plantations	0.66	0.38	0.26	1.69	NS
	Natural vegetation	0.57	0.27	0.16	1.69	
Tree density,‖ no.	Plantations	114.44	94.37	21.00	305.00	S
	Natural vegetation	56.87	23.99	23.00	119.000	
Bird species richness**	Plantations	17.33	4.84	10.00	31.00	NS
	Natural vegetation	18.66	7.10	4.00	31.00	

S, Plantations and natural vegetation differ significantly at $P < 0.01$; NS, not significant by t test.
*No. per 2400 m^2.
†$e^{H'}$, H' = Shannon–Weaver diversity index.
‡$1/\Sigma p_i^2$, where p is the proportion of individual plants in the ith height class.
§Mean of 120 points scored as 0, 1, 2, and 3.
¶Coefficient of variation (CV) for the 120 scores.
‖No. per 1000 m^2; plants ≥ 30-cm girth at breast height (GBH).
**No. per transect of 600 × 200 m.

The field data on woody plants and birds were collected by R.J.R.D. through strip transects encompassing all the vegetation zones of the district in the dry months between January 1986 and April 1988 (Fig. 1). The dry season covers the breeding period for most resident bird species, as well as the time spent by the winter migrants. Each of the 58-strip transects covered an area of 600 m × 200 m. Relative bird species richness for the different transects was assessed by following the uniform procedure of walking along the strip center at a pace of ≈10 m every 2 min during the morning hours of 0800–1000. The limit of 100 m on either side of the center line of the transects was fixed to allow for bird movement away from the observer and the range over which birds may be heard (9, 10). Birds were recorded as those sighted and/or heard on the transect, heard in the background apparently beyond transect limits, and flying overhead. This count was supplemented by more extensive, albeit less standardized, recording of all occurrences of bird species in the different vegetation zones of the district. Comparison of the more complete estimates of the bird species richness thus made with the transect estimates suggests that the birds recorded on the transect during the 2-hr sampling represent 30–40% of the total bird species in a locality. Species numbers estimated through recording those flying overhead and heard in the background were a more variable fraction of the total. Furthermore, the vegetation of Uttara Kannada is highly patchy, and the birds thus heard in the background beyond transect limits or flying overhead often represent habitat types other than those on the transect. Hence, all further analysis is based on the species of birds directly recorded (seen or heard) on the transect.

The transects covered two broad categories of vegetation—namely, natural forests and man-made plantations. The vegetation was characterized by the following attributes: species richness and abundance of woody plants, vertical stratification, extent of canopy cover, and tree [≥30 cm girth at breast height (GBH)] density. The woody plants were surveyed along a strip of 4-m width defined by using nylon ropes along the center of the transect on which birds were sampled. All individuals were identified and assigned to one of the following seven height classes: 0–1 m (seedlings), 1–2 m (shrubs), 2–4 m (understory), and the several canopy layers at 4–8 m, 8–16 m, 16–32 m, and >32 m. Vertical stratification in the present study thus reflects the proportion of woody plants in each height class rather than the amount of foliage, as is the case with the index of foliage height diversity introduced by MacArthur and MacArthur (11). The extent of canopy density at any point was scored as 0 when there was none overhead, 1 when canopies from adjacent trees barely met, 2 when the canopies overlapped with the

Table 2. Attributes of natural vegetation and associated bird species along a gradient of decreased moisture in the Uttara Kannada district

Attribute	Count, mean ± SD			Statistical significance		
	Evergreen (n = 20)	Semideciduous (n = 9)	Deciduous (n = 9)	E-S	E-D	S-D
Woody plant species	50.3 ± 5.97	36.33 ± 13.16	23.22 ± 4.2	S*	S*	S†
Woody plant species diversity	18.86 ± 6.47	15.33 ± 8.39	8.3 ± 1.38	NS	S*	S†
Vertical stratification	4.73 ± 0.66	4.02 ± 0.77	3.77 ± 0.83	S†	S*	NS
Canopy density	2.15 ± 0.55	1.31 ± 0.33	1.26 ± 0.191	S*	S*	NS
CV of canopy density	0.52 ± 0.34	0.67 ± 0.15	0.58 ± 0.78	NS	NS	NS
Tree density	68.7 ± 24.67	45.67 ± 16.35	41.78 ± 12.04	S†	S*	NS
Percentage deciduous‡	9.0 ± 5.4%	38.3 ± 10.0%	61.4 ± 9.3%	S*	S*	S*
Bird species richness	17.8 ± 6.90	18.78 ± 7.39	20.44 ± 6.88	NS	NS	NS

E-S, evergreen – semideciduous; E-D, evergreen – deciduous; S-D, semideciduous – deciduous; CV, coefficient of variation; S, significant; NS, not significant.
*$P < 0.01$.
†$P < 0.05$.
‡Percentage of total number of woody plant species.

Table 3. Correlation matrix of attributes of 38 samples of natural vegetation and 20 samples of plantations in the Uttara Kannada district

	WP species richness	WP species diversity	Vertical stratification	Canopy density	CV of canopy density	Tree density	Bird species richness
WP species		0.78*	−0.09	0.37	0.48	−0.25	0.39
richness		0.73*	0.28	0.53*	0.57*	0.06	0.17
WP species	0.83*		0.49	−0.39	−0.53	0.04	−0.38
diversity	0.85*		−0.09	−0.14	−0.29	−0.06	−0.35†
Vertical	0.51†	0.67*		−0.09	0.08	0.33	0.49‡
stratification	0.52*	0.44*		0.00	−0.27	−0.06	−0.24‡
Canopy	−0.45	−0.42	−0.27		−0.84*	0.68*	−0.28
density	0.70*	0.62*	0.56*		−0.64*	0.46*	0.15
CV of canopy	0.34	0.16	0.17	−0.83*		0.37	−0.24
density	−0.31	−0.37†	−0.49*	−0.77*		−0.14	0.07
Tree density	−0.45	−0.40	−0.08	0.76*	0.51†		0.22
	0.56*	0.49*	0.45*	0.83*	−0.69*		−0.28
Bird species	0.37‡	0.29‡	0.54†‡	−0.23	0.18	−0.03	
richness	−0.31‡	−0.44*‡	−0.39†‡	−0.36†	0.37†	−0.43*	

Simple correlations are to the left of and below the diagonal; partial correlations are to the right of and above the diagonal. For each attribute the upper row refers to plantations, and the lower row refers to natural vegetation. WP, woody plant; CV, coefficient of variation.
* and †Values of simple/partial correlation coefficients differ significantly from 0 at $P < 0.01$ and $P < 0.05$ level, respectively.
‡Values of simple/partial correlation coefficients differ significantly for plantations and natural vegetation at $P < 0.05$.

sky still showing through, and 3 when the sky was no longer visible through the overhead leaves. A total of 120 points at 5-m interval was scored in this way over the entire length of each transect. Tree density was estimated by using 10 m × 10 m quadrants. Ten quadrants (five on either side) were laid along the central line of the strip transects at intervals of 50 m, and all trees were counted.

Woody plant species diversity is computed as $e^{H'}$, where H' is the Shannon–Weaver index $-\Sigma\ p_i \ln p_i$, and p_i is the proportion of plants belonging to the ith species. Vertical stratification is computed by using the reciprocal Simpson index $1/\Sigma\ p_i^2$, where p_i is the proportion of woody plant individuals in the ith height class. Canopy cover has been estimated by averaging the density scores. The coefficient of variation in the canopy density is a measure of the extent of heterogeneity in the canopy cover over the transects. Tree density is expressed as the number of trees per 1000 m^2. All relationships have been analyzed by using the Pearson's product moment correlation coefficient r.

Table 4. Comparison of the number of species of humid evergreen forest birds of selected families in Western Ghats and Eastern Himalayas

Family	Exclusive to Western Ghats	Exclusive to Eastern Himalayas	Shared by both	Remarks
Phasianidae	1	6	0	Large ground bird
Columbidae	1	6	5	Large arboreal frugivore
Trogonidae	1	2	0	Large arboreal insectivore
Bucerotidae	2	4	1	Large arboreal frugivore
Capitonidae	2	4	0	Medium-sized frugivore
Picidae	1	6	5	Small-large insectivore
Corvidae	1	3	0	Large omnivore
Pycnonotidae	2	5	2	Medium-sized frugivore
Muscicapidae: *Timaliinae*	4	56	4	Sedentary insectivore
Total	15	92	17	

These data are from Ali and Ripley (19).

RESULTS AND DISCUSSION

Table 1 summarizes the characteristics of the vegetation for the 38 transects in natural vegetation and 20 transects in man-made plantations. As expected, the natural vegetation is, on an average, significantly more diverse as well as denser and structurally more complex, although its bird species richness levels are not significantly greater. This vegetation covers the whole range from evergreen through secondary evergreen, semideciduous, and deciduous types, with an increased proportion of deciduous species and decreased levels of woody plant species richness, density, and stratification as one progresses eastward to drier tracts (Table 2).

Our first notable result is that for natural vegetation, bird species richness significantly correlated negatively with woody plant species diversity as well as with vertical stratification, canopy density, and tree density. Bird species richness is, however, significantly correlated positively with the coefficient of variation of canopy density, suggesting that bird species richness increases with patchiness of tree cover

Table 5. Comparison of number of species of birds characteristic of drier habitats in Southeast Asia and adjoining tracts of Eastern Himalayas and the rest of the Indian subcontinent

Family/genera*	Southeast Asia/Eastern Himalayas	Indian subcontinent
Otitidae	2	6
Cursoridae	0	3
Alaudidae (*Erimopterix, Ammomanes, Galerida*)	1	7
Ploceidae (*Estrilda, Ploceus, Lonchura*)	11	11
Phasianidae (*Francolinus, Galloperdix, Perdicula*)	4	11

These data are from Ali and Ripley (19) and King and Dickinson (20).
*The genera have been separately indicated where the entire family is not considered.

Table 6. Habitat preference of the birds as percentage of species found in the different kinds of vegetation of the Uttara Kannada district

Birds	Habitat				
	Evergreen forest	Deciduous forest	Teak plantation	Eucalyptus plantation	Betel nut plantation
Closed forest specialist	77.27	40.91	37.03	4.76	35.29
Open forest specialist		9.1	14.81	19.05	11.76
Generalist using several habitats	22.73	50.00	48.15	76.19	52.94

These data are from Daniels *et al.* (3).

and presence of treefall gaps (12). Table 3 shows that the various attributes of natural vegetation strongly correlate with each other. Hence, we performed a partial correlation analysis to determine the relative significance of different vegetational attributes by excluding the effect of other attributes with the path analysis technique (13). This analysis reveals that the predominant influence is that of tree species diversity: the more diverse natural vegetation supports a significantly lower number of bird species.

The second notable result is that the man-made plantations differ from natural vegetation in this regard. In these plantations bird species richness correlates positively with stratification. Furthermore, the levels of positive correlations for plantations between bird species richness and woody plant species richness and woody plant species diversity significantly differ from the negative correlations obtained for the natural vegetation. As for natural vegetation, woody plant species richness, diversity, and vertical stratification positively correlate among themselves, whereas the mean of canopy density negatively correlates with its coefficient of variation.

The biota of Uttara Kannada district, thus, exhibits two trends that are more widely known and one that is only occasional. (*i*) The first, near universal trend is that of increase in plant species diversity coupled with greater levels of vertical stratification along the gradient of increased availability of moisture in the natural vegetation. In the tropical latitudes the proportion of evergreen plant species increases along the same gradient, so that the moister forest vegetation dominated by evergreen plants is more stratified and richer in woody plant species (Table 2). (*ii*) Bird species diversity is generally positively correlated with woody plant species diversity and/or stratification (11, 14, 15). (*iii*) This trend holds for the plantations of Uttara Kannada but is reversed for the natural vegetation, so that the more stratified and diverse evergreen forest vegetation harbors fewer bird species compared with the less stratified and less diverse deciduous vegetation of drier tracts.

The explanation for the lower level of bird species richness in the structurally more complex and diverse vegetation could lie in the smaller size of the potential pool of colonizers for such vegetation. Indeed, such an effect has been noted both for continental (Patagonia in South America) and island (West Indies) bird faunas (16, 17). We might, therefore, expect that the bird fauna of evergreen forests of Uttara Kannada derives from a smaller pool of potential colonizers in comparison with the drier forests. This prediction is related to the fact that the evergreen forests of Uttara Kannada are part of the evergreen forest vegetation of the Western Ghats, constituting a relatively restricted habitat island (64,750 km^2) at a great distance (1500 km) from the larger contiguous tract of evergreen vegetation in the Eastern Himalayas and Southeast Asia. On the other hand, the deciduous forest vegetation of Uttara Kannada is part of and contiguous with the large tract of deciduous and scrub vegetation (2,774,850 km^2) that covers most of the Indian subcontinent (18).

The bird fauna of the Western Ghats is, indeed, impoverished, especially with respect to land birds in comparison with the Eastern Himalayas, although the latter region is slightly smaller in area (19, 20). Thus, Western Ghats harbor a total of 507 species, of which 363 are land birds, while the Eastern Himalayas harbor 536 species, 523 of which are land birds. Table 4 further compares these two bird faunas with respect to families particularly characteristic of humid forests. This count leaves out bird species characteristic of altitudes >2500 m because the Western Ghats are almost entirely confined to lower elevations. Such a comparison reveals that larger sized birds, frugivores, and, above all, sedentary insectivores belonging to the subfamily Timaliinae are very poorly represented on the Western Ghats. In fact, Western Ghats harbor only 200 species characteristic of evergreen forests. This impoverishment is analogous to that noted by Terborgh and Winter (21), who conclude that members of families Phasianidae, Picidae, Timaliinae, and Bucerotidae are especially prone to extinction on land-bridge islands. We have no evidence as to whether members of these families never reached the Western Ghats or became extinct subsequently, perhaps with shrinkage in overall area of the evergreen forest tracts after reduction in rainfall. It is, nevertheless, likely that members of Timaliinae (babblers and laughing thrushes), being highly sedentary, territorial, and social birds, are very poor dispersers and may have never reached the Western Ghats.

Table 7. Food preferences of birds as percentages of species in the different kinds of vegetation of the Uttara Kannada district

Food preference	Vegetation				
	Evergreen forest	Deciduous forest	Teak plantation	Eucalyptus plantation	Betel nut plantation
Predominantly frugivores	45.45	22.73	22.22	14.29	5.88
Predominantly insectivores	50.00	59.09	62.96	71.43	76.47
Predominantly herbivores	4.55	13.64	11.11	9.52	11.76
Omnivores	0.00	0.00	3.70	4.76	5.88

These data are from Daniels *et al.* (3).

Although the evergreen forests of Western Ghats are thus impoverished of birds characteristic of humid forests, the Indian subcontinent is rich in birds characteristic of drier vegetation. This fact is emphasized in Table 5, which compares the number of species in selected genera and families for the Indian subcontinent (excluding Eastern Himalayas) with Southeast Asia along with the adjacent Eastern Himalayas—the two tracts having areas of comparable extent (19, 20). The size of species pool of drier forests, scrub, and secondary vegetation of peninsular India exceeds 275, substantially larger than the species pool of 200 characteristic of evergreen forests of Western Ghats (19). Hence, the evergreen forest avifauna of Uttara Kannada, subject to lower immigration pressure, may have coadapted to be saturated at a relatively low level of species richness when compared with that of drier tracts, subject to immigration pressure from a larger species pool. This fact could account for the inverse relationship between bird species richness and woody plant species diversity or stratification in the natural vegetation of Uttara Kannada.

In an earlier study from the same district (3), plantations were shown to exhibit levels of bird species richness not significantly different from those of the natural forests. The bird communities of plantations of Uttara Kannada closely resemble those of the drier forest tracts (Tables 6 and 7). This result is to be expected because plantations are closer to the deciduous forests in the scarcity of plant species bearing fleshy fruits, in their relatively simple structure, and in their low woody plant species diversity. Sharing the richer bird species pool with deciduous forests, the plantations exhibit the commoner trend of an increase in bird species richness with greater stratification of the woody vegetation.

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