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Impact of habitat disturbance on the distribution of endemic species of small mammals and birds in a tropical rain forest in Sri Lanka

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Abstract: We tested whether species endemic to Sri Lanka were less able than non-endemics to tolerate disturbed habitats. Small mammals were surveyed in four habitat types along a disturbance gradient (unlogged forest, selectively logged forest, cultivated areas and areas abandoned after cultivation) within and around the Sinharaja rain forest in south-west Sri Lanka. Twenty 90-m × 40-m plots were live trapped in each of these habitat types. Twelve taxa: nine rodents (*Srilankamys ohiensis, Rattus rattus kelaarti, R. r. kandianus, Mus mayori, M. cervicolor, Bandicota indica, Funambulus layardi, F. sublineatus* and *F. palmarum*) and three insectivores (*Crocidura miya, Suncus zeylanicus* and *Feroculus feroculus*) were recorded. Of these, five were endemic to Sri Lanka at the species level (species confined to the island) and six at subspecies level (subspecies confined to the island; other subspecies occurring on the Indian subcontinent). Species richness of small mammals decreased with the magnitude of forest disturbance. The endemic species selectively utilized sites within the forest whilst the majority of the other taxa used both forest and non-forest habitat types or were restricted to the latter. Bird surveys were carried out in the same plots, using sightings and calls. Sixty-six bird species were recorded, of which 21 were endemic species. Twenty endemic bird species preferentially used sites within the forest. The findings suggest that the forest-dwelling endemic species of both small mammal and bird encounter difficulties in tolerating modified landscapes, whilst other taxa are less affected. This highlights the vulnerability of endemic species to forest conversion.

Key Words: disturbance gradient, rodents, shrews, species diversity, species richness, Sinharaja

INTRODUCTION

Sri Lanka is a biologically diverse island with a rich complement of endemic species, most of which are concentrated in the rain forests of the south-west. These forests are present as scattered patches numbering around 200, with many of them only a few hundred hectares in extent, and surrounded by villages and agricultural plantations (IUCN 1997). The high degree of endemism within the rain forest has led to south-west Sri Lanka being named as a biodiversity hotspot (Myers 1990, Myers *et al.* 2000). Cincotta *et al.* (2000) have shown that south-west Sri Lanka and the Western Ghats of India have the highest human population densities of all the hotspots.

Environmental perturbations wrought by expanding human populations have caused natural distribution patterns of species to change at unprecedented rates; some species have become scarcer and others expanded their ranges (Harvey & May 1997). When natural habitats are disturbed, the species that have restricted distributions, particularly the endemics, often lack adaptability and hence are less able to tolerate the modified conditions than are widespread species (Goodyear 1992). Analysis of the distribution across a disturbance gradient would thus provide valuable insights into the ways in which species are affected (Diffendorfer *et al.* 1995, Nupp & Swihart 1996). Our objective was to investigate the impact of anthropogenic disturbance on the distribution of endemic vertebrates by analysing their distribution across a disturbance gradient within and around the Sinharaja rain forest in Sri Lanka. More precisely, we aimed to test whether endemics were less able than non-endemics to tolerate disturbed habitats.

In this paper, species that are restricted to Sri Lanka will be referred to as endemic while those species also occurring in the Indian subcontinent will be referred to as non-endemic. Thus, where a subspecies is endemic to

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Sri Lanka, and the species is represented by other subspecies in the Indian subcontinent, the species is considered non-endemic although the subspecies is endemic.

Small mammals were selected as the main study group, and surveys were undertaken across four habitat types that represented varying levels of human disturbance. The basic ecology of many animal groups, small mammals in particular, occurring in the Sri Lankan rain forests remains largely unknown since previous studies were typically simple assessments of species richness. Apart from some observations by Kotagama & Karunaratne (1983), no studies have investigated habitat usage patterns of endemic species. In order to generate a broader picture of the effects of disturbance on forest-dwelling vertebrates, our investigation was extended to include a survey of birds within the same sampling areas. The selected non-forest sites were located around the forest, but extended no more than 2 km from the forest boundary. Therefore the information gathered enables us to offer preliminary predictions about the ability of forest species successfully to colonize surrounding areas, should their natural habitat be lost.

METHODS

Study site

The Sinharaja forest is located in the wet zone in south-west Sri Lanka (6° 21′–26′ N, 80° 21′– 34′ E). The forest is of special interest as it represents a biome that dates back in its evolutionary history to Gondwanaland and is rich in biodiversity and endemism. Annual rainfall ranges from 3750–5000 mm and the mean monthly temperature ranges from 18–27 °C. Much of the precipitation comes during the periods of the south-west monsoon (May–July) and the north-east monsoon (November–January). The north-western section of the rain forest is wet evergreen forest. The vegetation of the eastern side of the forest, at a higher altitude, is essentially transitional between the lowland wet evergreen and the tropical montane forest types (IUCN 1993). The forest was designated a Biosphere Reserve under UNESCO's Global Network of Biosphere Reserves. In 1988, the forest was declared a National Heritage Wilderness Area by the government of Sri Lanka, and subsequently as a Natural World Heritage Site by UNESCO. The total area of the forest is 11 331 ha, of which about 2200 ha had earlier been selectively logged (IUCN 1993).

Selected habitats

Four major habitat types, ranging from undisturbed forest to habitats subject to varying levels of human disturbance, were selected within the rain forest and surrounding areas. They were (1) Unlogged habitat: consisting of pristine closed-forest areas with a relatively dense canopy and trees of large height and girth. Tree heights of the multi-storeyed forest ranged from 10 to 40 m. The undergrowth was sparse except in the few places with canopy gaps. Some of the unlogged sites selected were located near the periphery of the forest. (2) Selectively logged habitat: areas of the forest that had been selectively logged in the 1970s. These areas consisted of smaller trees with patchy canopy and the undergrowth was denser than in unlogged areas. In places where tree growth following felling resulted in canopy closure, the ground vegetation and general conditions resembled those of the unlogged areas. (3) Abandoned habitat: border areas of the forest that had earlier been cleared by villagers, cultivated with cash crops and subsequently abandoned. The areas selected for this study had been abandoned for over 5 y. Most of these sites are now in scrub, covered by the fern *Dicranopteris linearis* (Burm. f.) Underwood and herbaceous species. All the selected sites were located outside the forest, within 2 km of the forest boundary. (4) Plantation habitat: border areas which had been in scrub as in (3) above and which were later used for raising plantations of pine, rubber, tea or cinnamon, as monocultures. As with the abandoned sites, the selected plantation sites were located outside the natural forest, no further than 2 km from the forest boundary, and were under management.

Small mammal survey

The distribution of small mammals was determined through live trapping conducted in the four selected habitats. Twenty plots were randomly located in each of the four habitats (total of 80 plots) and trapping grids were established. The plots were located at least 500 m from each other, to minimize the likelihood of a particular individual being caught in more than one grid. Each grid was trapped for four consecutive days from May to August, 1998 or 1999. Folding aluminium Sherman live traps (8 × 9 × 23 cm in size) were used. The trapping grid in each plot spread over 90 m × 40 m and 48–50 traps were laid in each plot. Traps were baited with lightly charred coconut kernel and placed on the ground at each trap station, at 10-m intervals. The traps were checked and rebaited each morning between 07h00 and 12h00. Upon first capture, each individual was marked by toe-clipping for identification (in conformity with the guidelines approved by the American Society of Mammalogists 1998).

To check whether endemic mammals have narrower habitat usage than non-endemics, the Shannon–Wiener Index value [$H' = -\Sigma(p_i \log p_i)$] was calculated for each

Table 1. Summary of the distribution of small mammals, listed in standard taxonomic order, captured in the four selected habitat types in and around the Sinharaja forest. Nomenclature follows Phillips (1980). The total number of animals captured in 20 sampling plots, in each habitat type, is shown, as is the number of trap nights in parentheses at the head of each column. In parentheses after the habitat totals are mean abundances of the species (mean number of individuals captured per 100 trap nights) for each habitat type. For species where >10 animals were trapped, the raw data were analysed by one-way ANOVA and superscripts beside means indicate the results of one-way ANOVA followed by Tukey's pair-wise comparisons. Different superscript letters indicate significant differences in abundance between habitats.

Species	Total	Unlogged (3992)	Logged (4000)	Abandoned (3992)	Plantation (3984)
+Flame-striped jungle squirrel *Funambulus layardi*	11	7 (0.18^{a})	4 (0.10^{ab})	–(0^{b})	–(0^{b})
+Dusky-striped jungle squirrel *Funambulus sublineatus*	8	–(0)	7 (0.18)	1 (0.03)	–(0)
+Western Ceylon palm squirrel *Funambulus palmarum*	6	–(0)	–(0)	3 (0.08)	3 (0.08)
*Sri Lanka bicoloured rat *Srilankamys ohiensis*	83	50 (1.25^{a})	33 (0.83^{a})	–(0^{b})	–(0^{b})
+Ceylon highland rat *Rattus rattus kelaarti*	44	14 (0.35^{a})	29 (0.72^{b})	1 (0.03^{a})	–(0^{a})
+Common house rat *R. r. kandianus*	207	52 (1.30^{ab})	25 (0.63^{b})	65 (1.63^{a})	65 (1.63^{a})
*Bicoloured spiny rat *Mus mayori*	173	73 (1.83^{a})	70 (1.75^{a})	21 (0.53^{b})	9 (0.23^{a})
+Ceylon field mouse *Mus cervicolor*	71	–(0^{a})	–(0^{a})	27 (0.68^{b})	44 (1.10^{b})
*Ceylon long-tailed shrew *Crocidura miya*	13	11 (0.27^{a})	2 (0.05^{b})	–(0^{b})	–(0^{b})
*Kelaart's long-clawed shrew *Feroculus feroculus*	2	2 (0.05)	–(0)	–(0)	–(0)
*Ceylon jungle shrew *Suncus zeylanicus*	5	2 (0.05)	3 (0.08)	–(0)	–(0)
Indian bandicoot *Bandicota indica*	2	–(0)	1 (0.03)	–(0)	1 (0.03)
Species richness		8	9	6	5
Number of animals	625	211	174	118	122
Number of captures	791	280	215	154	142

* Endemic species; +, Endemic subspecies.

taxon (Zar 1999). We used the number of individuals captured per trap night as abundance, to compute the proportional abundance (p_i) of a taxon in a given habitat. As the magnitude of H′ is affected by the number of categories k (in this case, the number of habitat types), the J′ values, termed as evenness or relative diversity ($J' = H'/\log k$), which expresses the diversity as a proportion of the maximum possible diversity (Zar 1999), were calculated.

Bird survey

The methodology adopted for the bird study was designed to identify differences in species distributions in relation to habitat disturbance. Bird recordings were conducted in the 80 plots used for the small-mammal survey, during April to August 1999 and April and May 2000. Sampling was carried out from the centre of each grid set up for small-mammal trapping, for a block of 30 min on each of two days between 07h00 and 11h30. The number of individuals of a species observed or heard within an unlimited radius was recorded and a species-list was constructed for each plot. The sampling procedure employed for the birds allowed us to assess between-habitat differences in the abundance of the species but did not (and was not intended to) allow us to compare the abundance of different species (Bibby *et al.* 2000).

RESULTS

Species richness and abundance of small mammals in different habitats

Twelve taxa of small mammal, nine rodents and three insectivores, were recorded during this survey (Table 1). Of the 12 taxa, all of which were indigenous to Sri Lanka, five (two rodents and three insectivores) were endemic and seven (all rodents) non-endemic at species level. Of the non-endemic species, six are represented in Sri Lanka by subspecies endemic to the island.

Table 1 summarizes the distribution of small mammals in the four selected habitat types. The total number of species recorded in the two forest habitats (ten species) was greater than the number of species recorded from the two non-forest habitats (seven species). Also, the forest habitats supported a higher number of endemic species (five) than the non-forest habitats (one). Of the forest habitats, the unlogged sites, where all five endemic species occurred, had a higher diversity of endemic species than the selectively logged sites that had four. Of the five endemic species, four (*Srilankamys ohiensis*, *Crocidura miya*, *Feroculus feroculus* and *Suncus zeylanicus*) were entirely restricted to the forest habitats.

The mean numbers of individuals captured per 100 trap nights, for the seven taxa of small mammals in which more than ten individuals were recorded, were analysed using one-way ANOVA and the Tukey's pair-wise comparison test to identify the habitat/s in which a given taxon was significantly more abundant. The other five taxa were not analysed statistically because of the low numbers of captures (Table 1). Among endemics *Srilankamys ohiensis* was significantly more abundant in forest habitats, with no difference evident between the unlogged and logged habitats (one-way ANOVA $F_{3,76} = 14.7$, $P < 0.0001$, Table 1). Similarly, *Mus mayori* attained significantly higher numbers (over 80% of the individuals trapped) in forest habitats ($F_{3,76} = 15.0$, $P < 0.0001$, Table 1). Another endemic, *Crocidura miya*, showed differences in abundance between habitats ($F_{3,76} = 4.25$, $P < 0.01$) and was most abundant in unlogged forest (Table 1).

In contrast to the three endemics above which were most numerous in forest habitats, the non-endemic species showed various habitat usage patterns, with a notably clear distinction in the distribution of the two subspecies of *Rattus rattus*. Abundance of *Rattus r. kelaarti* varied between habitats (one-way ANOVA $F_{3,76} = 11.7$, $P < 0.0001$) and was highest in logged areas (Table 1). *Rattus r. kandianus*, on the other hand, showed much less variation in abundance between the four habitats ($F_{3,76} = 2.89$, $P < 0.04$). The abundance of *Mus cervicolor*, another non-endemic, was significantly higher in non-forest areas ($F_{3,76} = 9.27$, $P < 0.0001$), with plantation sites slightly preferred. The squirrel *Funambulus layardi* also showed variation between habitats ($F_{3,76} = 5.74$, $P < 0.005$), and was most abundant in unlogged forest (Table 1). Of the other two squirrel species, *F. sublineatus* was restricted to forest habitats (with the exception of a single individual of the latter which was recorded from an abandoned site) and *F. palmarum* was restricted to non-forest habitats.

Across the four habitat types, the endemic species showed significant differences in overall abundance to the non-endemic species ($\chi^2 = 161$, df = 3, $P < 0.001$). The total abundance of endemic species in the four habitat types (276 individuals) was somewhat lower than that of the non-endemic species (349 individuals). Taking the forest and non-forest habitats separately, the forest habitats contained more than eight times as many individuals of endemic species (246) as the non-forest habitats (30) ($\chi^2 = 167$, df = 1, $P < 0.001$). The opposite trend applied to non-endemic species, with the non-forest habitats supporting a significantly larger number of individuals (210) than the forest habitats (139) ($\chi^2 = 14.0$, df = 1, $P < 0.01$).

Table 2. Shannon–Wiener evenness values, $J' = [-\Sigma(p_i \log p_i)]/\log k$, for the small-mammal taxa recorded in the four selected habitat types in the Sinharaja forest area (p_i, proportional abundance of a species; k, number of habitats).

Species	J′
Rattus rattus kandianus	0.96
**Mus mayori*	0.82
Rattus rattus kelaarti	0.52
Bandicota indica	0.50
Funambulus palmarum	0.50
**Suncus zeylanicus*	0.49
**Srilankamys ohiensis*	0.48
Mus cervicolor	0.48
Funambulus layardi	0.47
**Crocidura miya*	0.32
Funambulus sublineatus	0.27
**Feroculus feroculus*	0.00

* Endemic species.

The median value of the Shannon–Wiener evenness value (Table 2) for the seven non-endemics was 0.50 (range 0.27–0.96) and for the five endemics 0.48 (range 0.00–0.82) but the difference is not significant (Mann–Whitney $U = 19$; $P > 0.05$), perhaps because the number of species sampled is low. However, it is interesting to note that the non-endemic *Rattus rattus kandianus* had the highest evenness value (0.96) indicating very wide habitat usage.

Capture rates in the different habitats

A total of 625 individuals was captured in 15 968 trap nights in 80 sampling plots, within the four selected habitat types. The 625 individuals were captured a total of 791 times, an overall capture rate of 5.0% (number of captures per 100 trap nights). In general, forest habitats had higher capture rates (6.2%) than non-forest habitats (3.7%) and there was a significant difference between the number of captures in the four habitat types ($\chi^2 = 61.1$, df = 3, $P < 0.01$), with the highest capture rate, 7.0%, in the unlogged forest and the lowest, 3.6%, in the plantation sites.

Among the endemic species, *Mus mayori* was captured in 90% of the plots in the unlogged forest and 100% of the plots in the logged forest. Capture rates per plot were nowhere near as high among the other endemic species. *Srilankamys ohiensis* was recorded in just over half of both the unlogged and logged sites. The three species of shrew, *Crocidura miya*, *Suncus zeylanicus* and

Table 3. Habitat utilization of endemic and non-endemic bird species inhabiting areas in and around Sinharaja forest. The table shows, for the more numerous 53 species (>10 individuals recorded), the number of species that were significantly more abundant, as determined by one-way ANOVA, in either forest (unlogged and logged) or non-forest (abandoned and plantation) habitats, or showed no significant difference in abundance between the habitats. Of the 13 less-numerous species (<10 individuals recorded), the one endemic was restricted to forests while the numbers of non-endemic species restricted to forest, restricted to non-forest or recorded in both habitats were two, four and six respectively. Detailed results are provided in Appendix 1.

	Higher abundance in forests	Higher abundance in non-forests	No difference in abundance
Endemics	19	–	1
Non-endemics	10	7	16

Feroculus feroculus, were recorded in less than a quarter of the plots surveyed within the forest. This was probably due to the low densities of these species, even in their preferred habitats.

Species richness and abundance of birds

In the same 80 sampling plots as used for the small mammal survey, 66 species of bird, 21 endemic species and 45 non-endemic species, were recorded. For each species, the mean number of individuals per plot in each habitat was calculated (Appendix 1). In the bird survey, as for the small mammals, differences in the distribution patterns between endemic and non-endemic species were evident (Table 3).

Endemic bird species richness at both unlogged and logged sites was greater than that of the abandoned and plantation sites. In fact, a large majority of the endemics (20 of the 21 species recorded) were more common in, or restricted to, the forest habitats. In contrast, nearly 75% of the non-endemic species were restricted to the non-forest habitats or were roughly equally common in forest and non-forest habitats. Of the 45 non-endemic species recorded, only 12 preferentially utilized habitats within the forest.

DISCUSSION

The results of the survey indicate that the assemblages of both small mammals and birds within the forest differ substantially from the assemblages in the bordering non-forest areas, and that the distribution patterns of the endemic species are different from those of the non-endemic species. Forest assemblages had higher species diversity than non-forest assemblages. Changes in community structure between habitats are expected to reflect ecological characteristics that allow species to exist and coexist (Connell & Orians 1964). The higher species diversity in the forests, compared to the non-forest habitats, is therefore probably partly a consequence of the greater complexity of vegetation structure within rain forests, which creates a greater variety of niches for a wider range of animal species (Gubista 1999).

While recognizing that habitat changes within a forest affect the abundance and composition of the fauna within it (Nupp & Swihart 1996, Yahner 1988), the present investigation reveals a sharp distinction in the response to habitat change between endemic and non-endemic species. The endemic species showed a distinct preference for the less-disturbed forest and the non-endemic species displayed a greater ability to use human-modified habitats. Most of the non-endemics, even those belonging to endemic subspecies, either used both forest and non-forest habitats or preferentially utilized the non-forest habitats. Similar contrasts in habitat usage patterns of endemic and non-endemic species have also been reported by other workers for a wide range of taxonomic groups – plants (Smith 1997), bats and small mammals (Giraudoux *et al*. 1998, Heaney *et al*. 1989, Stephenson 1995), birds (Sankaran 1997), and butterflies (Lewis *et al*. 1998, Thomas 1991).

The scarcity of endemic species in disturbed habitats hints at their habitat sensitivity and their inability to invade modified landscapes (Williams & Pearson 1997). The present investigation shows that this is so even in modified habitats lying adjacent to native forest habitats. It is interesting to note that observations made in Sinharaja in 1982, just 5 y after logging was suspended, indicated the absence of *Srilankamys ohiensis* and *Crocidura miya* in selectively logged areas (Kotagama & Karunaratne 1983). These sites were also sampled during the present study, and the two species have now reinvaded the selectively logged areas following a long period during which no logging operations were carried out. Over the years the logged forests have regenerated and have regained much of their original vegetation structure and composition and presumably now provide congenial habitats for these species. As for *Rattus rattus*, Kotagama & Karunaratne (1983) observed that *R. r. kandianus* substantially increased where trees had been felled. This is not surprising because it has been demonstrated that disturbance may be beneficial for such commensal species that are well adapted to utilize man-modified habitats (Goodman 1995, Lewis *et al*. 1998, Stephenson 1993).

Previous observations made on birds in Sinharaja are consistent with those of the present study (Kotagama 1985). Kotagama reported drastic changes in species assemblages, from forest birds to village birds, in response to selective logging. He also documented how logging caused immediate alterations in the natural bird community of the logged areas by facilitating the influx of non-endemic species into the forest.

The present investigation shows that, while endemic species are present within the forest, including within areas that had been selectively logged many years earlier, they are virtually absent in adjacent deforested areas. Furthermore, within the forest, the abundance of most endemic species was greater than the abundance of related non-endemic species. The differential habitat utilization patterns between these two groups are also suggested by the differences in the evenness values between the endemic and non-endemic taxa. These findings are broadly consistent with studies carried out elsewhere where it has been demonstrated that endemic species, though restricted in distribution, may, in their particular preferred habitats, be found in greater abundance than widely distributed species (Lewis *et al.* 1998). However, in the present study, the capture rates per plot of the endemic small mammals suggested, with one exception, moderate to low densities within the forest, their preferred habitat. This contributes to their vulnerability in the face of deforestation.

This study has shown that many endemic species inhabiting the rain forest are unable to utilize non-forest habitats resulting from deforestation and conversion of the land to other forms of land use. In Sinharaja, selective logging took place only in a part of the forest, leaving much of it undisturbed, and the endemic species were, after many years, able to return from the contiguous untouched forest to the logged forest after it had recovered. The low tolerance of endemic species to habitat changes compared with the non-endemic species might mean that they are the first to disappear from the community when habitat destruction, particularly of pristine habitats, occurs. Hence, our findings concur with those of other authors that both deforestation and widespread logging in tropical rain forests lead to both diminished species diversity and local extinction of the endemic species.

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LITERATURE CITED

AMERICAN SOCIETY OF MAMMALOGISTS 1998. Guidelines for the capture, handling, and care of mammals as approved by the American Society of Mammalogists. *Journal of Mammalogy* 79:1416–1431.

BIBBY, C. J., BURGESS, N. D. & HILL, D. A. 2000. *Bird census techniques.* (Second edition). Academic Press, London. 302 pp.

CINCOTTA, R. P., WISNEWSKI, J. & ENGLEMAN, R. 2000. Human population in the biodiversity hotspots. *Nature* 404:990–992.

CONNELL, J. H. & ORIANS, G. E. 1964. The ecological regulation of species diversity. *The American Naturalist* 18:399–414.

DIFFENDORFER, J. E., GAINES, M. S. & HOLT, R. D. 1995. Habitat fragmentation and movements of three small mammals (*Sigmodon, Microtus* and *Peromyscus*). *Ecology* 76:827–839.

GIRAUDOUX, P., QUERE, J. P., DELATTRE, P., BAO, G., WANG, X., DAZHONG, S. H. I., VULTON, D. & CRAIG, P. S. 1998. Distribution of small mammals along a deforestation gradient in southern Gansu, Central China. *Acta Theriologica* 43:349–362.

GOODMAN, S. M. 1995. *Rattus* on Madagascar and the dilemma of protecting the endemic rodent fauna. *Conservation Biology* 9:450–455.

GOODYEAR, N. C. 1992. Spatial overlap and dietary selection of native rice rats and exotic black rats. *Journal of Mammalogy* 73:186–200.

GUBISTA, K. R. 1999. Small mammals of the Ituri forest, Zaire: diversity and abundance in ecologically distinct habitats. *Journal of Mammalogy* 80:252–262.

HARVEY, P. H. & MAY, R. M. 1997. Case studies of extinction. *Nature* 385:776–777.

HEANEY, L. R., HEIDEMAN, P. D., RICKART, E. A., UTZURRUM, R. B. & KLOMPEN, J. S. H. 1989. Elevational zonation of mammals in the central Philippines. *Journal of Tropical Ecology* 5:259–280.

IUCN 1993. *A management plan for the conservation of the Sinharaja forest.* IUCN – The World Conservation Union – Sri Lanka, Colombo.

IUCN 1997. *Designing an optimum protected areas system for Sri Lanka's natural forests – Volume 1.* Food and Agriculture Organization of the United Nations.

KOTAGAMA, S. W. 1985. Fauna of the wet zone. *Sri Lanka Forester* 12:142–144.

KOTAGAMA, S. W. & KARUNARATNE, P. B. 1983. Checklist of the mammals (Mammalia) of the Sinharaja MAB Reserve. *Sri Lanka Forester* 11:29–35.

LEWIS, O. T., WILSON, R. J. & HARPER, M. C. 1998. Endemic butterflies on Grande Comore: habitat preferences and conservation priorities. *Biological Conservation* 85:113–121.

MYERS, N. 1990. The biodiversity challenge: expanded hotspots analysis. *The Environmentalist* 10:243–256.

MYERS, N., MITTERMEIR, R. A., MITTERMEIR, C. G., DA FONSECA, G. A. B. & KENT, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403:853–858.

NUPP, T. E. & SWIHART, R. K. 1996. Effect of forest patch area on population attributes of white-footed mice (*Peromyscus leucopus*) in fragmented landscapes. *Canadian Journal of Zoology* 74:467–472.

PETERS, J. L. 1934–1986. *Check-list of Birds of the World, vols II–XV.* Harvard University Press, Cambridge, MA.

PHILLIPS, W. W. A. 1980. *Manual of the mammals of Sri Lanka – part II.* Wildlife and Nature Protection Society of Sri Lanka, Colombo. 267 pp.

SANKARAN, R. 1997. Developing a protected area network in the Nicobar Islands: the perspective of endemic avifauna. *Biodiversity Conservation* 6:797–815.

SMITH, D. 1997. The progress and problems of the "Endemic Section" of St Helena Island. *Oryx* 31:218–224.

STEPHENSON, P. J. 1993. The small mammal fauna of Reserve Speciale d'Analamazaotra, Madagascar: the effects of human disturbance on endemic species diversity. *Biodiversity Conservation* 2:603–615.

STEPHENSON, P. J. 1995. Small mammal microhabitat use in lowland rainforests of northeast Madagascar. *Acta Theriologica* 40:425–438.

THOMAS, C. D. 1991. Habitat use and the geographic ranges of butterflies from the wet lowlands of Costa Rica. *Biological Conservation* 55:269–281.

WILLIAMS, S. E. & PEARSON, R. G. 1997. Historical rainforest contractions, localized extinctions and patterns of vertebrate endemism in the rainforest of Australia's wet tropics. *Proceedings of the Royal Society of London* 264:709–716.

YAHNER, R. H. 1988. Changes in wildlife communities near edges. *Conservation Biology* 2:333–338.

ZAR, J. 1999. *Biostatistical analysis.* (Fourth edition). Prentice Hall International, London. 663 pp.

Appendix 1. The mean abundance of bird species in the four selected habitat types (i.e. the mean number of individuals recorded during a period of 30 min in the 20 sampling plots in each of the habitats) in and around the Sinharaja forest. Species are listed in standard taxonomic order and nomenclature follows Peters (1934–1986). Only species for which more than ten individuals were recorded were analysed statistically and the results of the one-way ANOVA and Tukey's pair-wise comparison test are shown. Significant differences in abundance between habitats are indicated by different superscripts.

Species	Unlogged	Logged	Abandoned	Plantation	F	P
Black eagle *Ictinaetus malayensis*	0.08	0.0	0.15	0.13	1.30	0.28
Black-winged kite *Elanus caeruleus*	0.0	0.0	0.0	0.05	2.11	0.11
Crested serpent eagle *Spilornis cheela*	0.28	0.40	0.25	0.30	0.45	0.72
*Sri Lanka jungle fowl *Gallus lafayettii*	1.28[a]	1.10[a]	0.03[b]	0.0[b]	12.92	< 0.01
*Sri Lanka spur fowl *Galloperdix bicalcarata*	0.45[ab]	0.50[a]	0.0[b]	0.05[b]	4.97	< 0.05
*Sri Lanka wood pigeon *Columba torringtonii*	0.05	0.10	0.0	0.0		N/A
Spotted dove *Streptopelia chinensis*	0.0[a]	0.0[a]	1.88[b]	1.53[b]	7.64	< 0.01
Emerald dove *Chalcophaps indica*	0.10	0.15	0.08	0.20	0.46	0.71
Pompadour green pigeon *Treron pompadora*	0.05	0.15	0.13	0.15	0.36	0.78
Green imperial pigeon *Ducula aenea*	0.55[a]	0.58[ab]	0.55[a]	0.10[b]	3.43	< 0.05
*Sri Lanka lorikeet *Loriculus beryllinus*	0.38[ab]	0.45[a]	0.0[b]	0.08[b]	3.98	< 0.05
*Sri Lanka layards parakeet *Psittacula calthorpae*	0.23	0.48	0.0	0.0	5.57	< 0.01
Blossom-headed parakeet *Psittacula cyanocephala*	0.0	0.0	0.03	0.05		NA
*Red-faced malkoha *Phaenicophaeus pyrrhocephalus*	0.78[a]	1.00[a]	0.0[b]	0.0[b]	10.37	< 0.01
*Sri Lanka green-billed coucal *Centropus chlororhynchus*	0.38[a]	0.45[a]	0.0[b]	0.0[b]	6.55	<0.05
Common coucal *Centropus sinensis*	0.0[a]	0.0[a]	0.25[ab]	0.48[b]	5.48	< 0.05
M Red-winged crested cuckoo *Clamator coromandus*	0.0	0.03	0.0	0.0		NA
Indian koel *Eudynamys scolopacea*	0.0	0.0	0.0	0.05		NA
*Chestnut-backed owlet *Glaucidium castanonotum*	0.08[a]	0.18[ab]	0.0[b]	0.0[b]	4.56	< 0.01
Forest eagle-owl *Bubo nipalensis*	0.0	0.05	0.0	0.03		NA
Collared scops owl *Otus bakkamoena*	0.0	0.0	0.0	0.03		NA
Ceylon frogmouth *Batrachostomus moniliger*	0.03	0.0	0.0	0.03		NA
House swift *Apus affinis*	0.0[a]	0.05[a]	0.10[a]	0.19[b]	5.51	< 0.05
Ceylon trogon *Harpactes fasciatus*	0.48[a]	0.60[a]	0.0[b]	0.0[b]	11.99	< 0.01
Chestnut-headed bee-eater *Merops leschenaulti*	0.0[a]	0.0[a]	0.15[ab]	0.25[b]	3.93	< 0.05
*Sri Lanka grey hornbill *Ocyceros gingalensis*	0.43[a]	0.38[b]	0.0[c]	0.0[c]	20.05	< 0.01
*Sri Lanka yellow-fronted barbet *Megalaima flavifrons*	0.60[a]	0.40[a]	0.0[b]	0.0[b]	10.86	< 0.01
*Sri Lanka small barbet *Megalaima rubricapilla*	0.03	0.18	0.20	0.03	2.81	0.06
Brown-headed barbet *Megalaima zeylanica*	0.0	0.0	0.15	0.13	2.17	0.10
Lesser yellow-naped woodpecker *Picus chlorolophus*	0.05[a]	0.30[b]	0.0[a]	0.03[a]	10.17	< 0.01
Crimson-backed woodpecker *Chrysocolaptes lucidus*	0.38[a]	0.68[a]	0.0[b]	0.0[b]	11.97	< 0.01
Red-backed woodpecker *Dinopium benghalense*	0.0	0.0	0.15	0.10	1.76	0.16
M Yellow wagtail *Motacilla flava*	0.05	0.05	0.05	0.0		NA
Little minivet *Pericrocotus cinnamomeus*	0.25[ab]	0.52[a]	0.28[ab]	0.13[b]	3.37	< 0.05
Orange minivet *Pericrocotus flammeus*	0.13	0.15	0.15	0.0	1.56	0.27
*Black bulbul *Hypsipetes leucocephalus*	0.75[a]	0.73[a]	0.0[b]	0.0[b]	16.23	< 0.01
Black-capped bulbul *Pycnonotus melanicterus*	0.15[a]	0.38[b]	0.25[ab]	0.0[a]	3.25	< 0.05
Red-vented bulbul *Pycnonotus cafer*	0.0[a]	0.0[a]	0.78[b]	0.95[b]	13.63	< 0.01
Yellow-browed bulbul *Iola indica*	0.08	0.13	0.0	0.0	2.21	0.09
Jerdon's chloropsis *Chloropsis cochinchinensis*	0.13[ab]	0.25[a]	0.0[b]	0.0[b]	9.95	< 0.01
Common iora *Aegithina tiphia*	0.15	0.30	0.15	0.23	0.68	0.57
*Sri Lanka spotted-winged thrush *Zoothera spiloptera*	0.83[a]	0.80[a]	0.0[b]	0.0[b]	17.76	< 0.01
Scaly thrush *Zoothera dauma*	0.03	0.03	0.0	0.0		NA

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Appendix 1. Continued

Species	Unlogged	Logged	Abandoned	Plantation	F	P
Black robin *Saxicoloides fulicata*	0.0[a]	0.0[a]	0.28[b]	0.15[b]	3.45	< 0.05
M Brown flycatcher *Muscicapa dauurica*	0.0	0.13	0.0	0.05		NA
Tickell's blue flycatcher *Cyornis tickelliae*	0.38	0.30	0.30	0.0	2.29	0.09
M Paradise flycatcher *Terpsiphone paradisi*	0.43	0.68	0.25	0.40	2.21	0.09
*Ashy-headed laughing thrush *Garrulax cinereifrons*	2.55[a]	2.23[a]	0.0[b]	0.0[b]	15.66	< 0.01
*Brown-capped babbler *Pellorneum fuscocapillum*	0.88[a]	1.00[b]	0.18[c]	0.0[c]	4.47	< 0.05
*Rufous babbler *Turdoides rufescens*	5.30[a]	4.25[a]	0.03[b]	0.0[b]	25.83	< 0.01
Common babbler *Turdoides affinis*	0.0[a]	0.0[a]	2.15[b]	2.15[b]	7.64	< 0.01
Scimitar babbler *Pomotorhinus horsfieldii*	0.30[a]	0.28[a]	0.0[b]	0.03	5.97	< 0.05
Dark-fronted babbler *Rhopocichla atriceps*	0.30	0.65	0.35	0.35	0.41	0.75
Velvet-fronted nuthatch *Sitta frontalis*	0.30[a]	0.30[a]	0.0[b]	0.0[b]	3.40	< 0.05
Purple-rumped sunbird *Nectarinia zeylonica*	0.0	0.03	0.20	0.15	2.37	< 0.08
*Legge's flowerpecker *Dicaeum vincens*	0.40[a]	0.95[b]	0.0[c]	0.0[c]	12.68	< 0.01
*Sri Lanka hill white-eye *Zosterops ceylonensis*	0.75[a]	0.98[a]	0.0[b]	0.0[b]	8.86	< 0.01
Black-headed oriole *Oriolus xanthornus*	0.0	0.0	0.03	0.13		NA
M Brown shrike *Lanius cristatus*	0.0	0.13	0.0	0.05		NA
Ceylon crested drongo *Dicrurus paradiseus*	0.68[a]	0.70[a]	0.0[b]	0.0[b]	9.46	< 0.01
White-bellied drongo *Dicrurus caerulescens*	0.0[a]	0.0[a]	0.23[b]	0.63[c]	12.37	< 0.01
*Sri Lanka blue magpie *Urocissa ornata*	1.95[a]	5.03[b]	0.0[c]	0.0[c]	27.46	< 0.01
Jungle crow *Corvus macrorhynchos*	0.05	0.0	0.23	0.0		NA
*Sri Lanka white-headed starling *Sturnus senex*	0.58[a]	0.70[a]	0.0[b]	0.0[b]	5.55	< 0.05
*Sri Lanka hill-mynah *Gracula ptilogenys*	0.83[a]	0.70[a]	0.0[b]	0.0[b]	11.78	< 0.01
Common hill-mynah *Gracula religiosa*	0.15	0.43	0.20	0.15	1.31	0.28
No. of species recorded	45	50	31	30		

* Endemic species; M, migrant species; NA, species not statistically analysed.

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