Responses of small carnivores to rainforest fragmentation in the southern Western Ghats, India

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Abstract

Small carnivore abundance from track plot, camera-trap, and spot-lighting surveys were compared between a contiguous tract of tropical rainforest and 10 rainforest fragments in the southern Western Ghats, India. Although six species were recorded from the rainforests in this region, surveys targeted three nocturnal species. Small carnivore abundance was higher in contiguous rainforests, especially the endemic Brown Palm Civet *Paradoxurus jerdoni*, whose occurrence was positively influenced by food-tree densities and altitude, and was higher in medium-sized (51–100 ha) fragments adjoining shade-coffee plantations than the more isolated smaller and larger fragments. The omnivorous and widespread Small Indian Civet *Viverricula indica* and mongooses *Herpestes* spp. were more frequent in rainforest fragments than in the relatively undisturbed, large, contiguous tract of rainforest in Kalakad–Mundanthurai Tiger Reserve. Thus, small carnivores persist in fragmented landscapes with altered community structure, but long-term persistence may require protection of private fragments, fostering benign land-uses, and restoration of degraded areas.

Keywords: Anamalai hills, Kalakad–Mundanthurai Tiger Reserve, *Paradoxurus jerdoni*, plantations, *Viverricula indica*

Resumen

Se comparó la abundancia de pequeños carnívoros en una zona de pluvisilva tropical continua (no fragmentada) y 10 fragmentos de pluvisilva en los Ghats sudoccidentales, India, mediante rastreo de huellas, trampeo fotográfico y foqueos. Aunque se detectaron seis especies en la región, los muestreos estuvieron orientados a tres especies nocturnas. La abundancia de pequeños carnívoros fue mayor en la pluvisilva continua que en los fragmentos, especialmente la de la endémica civeta de Jerdon *Paradoxurus jerdoni*, cuya presencia estuvo positivamente influenciada por la densidad de árboles de los que se alimenta y la altitud. El indice de detección de esta especie fue más alto en fragmentos de tamaño medio (51–100 ha) adyacentes a plantaciones cafe de sombra que en los fragmentos más aislados bien fuesen de mayor o menor tamaño. La pequeña civeta indú *Viverricula indica* y las mangostas *Herpestes* spp. omnívoras y de amplia distribución, fueron más frecuentemente detectadas en los fragmentos de pluvisilva que en la zona de pluvisilva continua de la Reserva de Tigres Kalakad–Mundanthurai. Por tanto, los pequeños carnívoros subsisten en paisajes fragmentados en los que la estructura de la comunidad ha sido alterada, pero su supervivencia a largo plazo puede precisar la protección de fragmentos privados, el fomento de usos de suelo benignos, y la resturación de áreas degradadas.

Introduction

Habitat loss and fragmentation are the primary threats to tropical rainforest habitats and species. Studies on tropical rainforest fragmentation have shown that area of available habitat influences changes in plant and animal occurrences and densities, with larger areas usually containing a greater number of species (Laurance *et al*. 1997, Umapathy & Kumar 2000). However, small, isolated forest fragments are also repositories of tropical biodiversity (Turner & Corlett 1996). Species that are particularly negatively impacted by habitat fragmentation are those with specialised habitat requirements or large home-ranges (Laurance 1990, Chiarello 1999). Conversely, many species of frugivorous and folivorous birds and mammals may increase in abundance due to increase in some food resources associated with the openness of the habitat following disturbances (Leighton & Leighton 1983, Johns 1988, Struhsaker 1997). Moderate habitat disturbance often has a positive effect on small carnivorous mammals such as mongooses and civets, a majority of which are habit generalist (Oehler & Litvaitis 1996, Ray & Sunquist 2001).

Since many small carnivores play significant roles in the habitat as predators and seed dispersers, the disturbance or alteration of the small carnivore community due to fragmentation can impact ecosystem dynamics (Terborgh 1988, Dirzo & Miranda 1990, Redford 1992, Crooks & Soulé 1999). In tropical ecosystems, an understanding of the correlates of small carnivore distribution, persistence, or disappearance following habitat fragmentation is lacking. This is partly due to the intrinsic difficulties in assessing the occurrence and abundance of small carnivores that are nocturnal and cryptic, especially when the community is species-rich (Duckworth 1998). In order to effectively survey small carnivores, a combination of methods may have to be used (Zielinski & Kucera 1995, Foresman & Pearson 1998, Silveira *et al*. 2003). In south and south-east Asia, given the difficulties in survey and detection of these species, very little is known of their response to habitat alterations (Heydon & Bulloh 1996, Colón 2002).

The Western Ghats mountain range in India is a global biodiversity hotspot with a high diversity of plant and animal taxa, including small carnivores (Kumar *et al*. 2004, Mudappa in press). The Western Ghats, with an estimated four-fold increase in the number of forest fragments and an 83% reduction in the size of surviving patches between 1920 and 1990, and a very high human population density, is critically threatened by habitat degradation and fragmentation (Menon & Bawa 1997). The rainforests of the Western Ghats have six species of non-aquatic small carnivores including two endemic species (Nilgiri Marten *Martes gwatkinsi*, Brown Palm Civet *Paradoxurus jerdoni*), two endemic sub-species of species otherwise also occurring in Sri Lanka (Stripe-necked Mongoose *Herpestes vitticollis*, Brown Mongoose *H. fuscus*), and two geographically very widespread species (Small Indian Civet *Viverricula indica*, Leopard Cat *Prionailurus bengalensis*). Although a few surveys have been carried out on these species in

the Western Ghats, there have been no ecological or behavioural studies on any species except the Brown Palm Civet (Ashraf *et al*. 1993, Rajamani *et al*. 2002, Mudappa 2001, Mudappa in press).

This study in the Western Ghats of India is the first in tropical Asia examining the impact of rainforest fragmentation on small carnivores. Of particular interest were the distribution patterns and occurrence of the endemic Brown Palm Civet (see photograph), an important frugivore and seed-disperser in these rainforests and one of the species with the smallest distribution range among south Asia's carnivores (Rajamani *et al*. 2002). As rainforest fragmentation in the region is a major global conservation concern, we assessed changes in the occurrence and relative abundance of small carnivores in two major and contrasting tropical rainforest landscapes in the southern Western Ghats using a combination of methods such as camera trapping, track plots, and spot-lighting. We also identified habitat and site characteristics that determined small carnivore distribution, persistence, and abundance. Based on these results, the implications for conservation of small carnivores and the value of fragments for conservation in tropical landscapes are discussed.

Methods

Study area

The Western Ghats is a 1600 km long hill range running from the southern tip of the Indian peninsula at 8°N to the River Tapti at 21°N. The region between 8° and 11°N, known as the southern Western Ghats, has two important conservation regions in the Agasthyamalai and Anamalai hills containing high diversity tropical rainforest, classified as the mid-elevation (600–1400 m) tropical wet evergreen forest of the *Cullenia exarillata–Mesua ferrea–Palaquium ellipticum* type (Pascal 1988).

The Kalakad–Mundanthurai Tiger Reserve (KMTR, 895 km², 8°25'–53'N and 77°10'–35'E) in Tamil Nadu state is situated in the Agasthyamalai hills at the southern extremity of the Western Ghats (Fig. 1). KMTR, along with adjoining sanctuaries in Kerala state, includes over 400 km² of contiguous rainforests relatively undisturbed by human activities—one of the largest such tracts in the Western Ghats (Ramesh *et al*. 1997). The average annual rainfall within the rainforest tracts ranges between 2200 and 3500 mm. Small carnivore surveys were carried out around three sites varying in altitude within KMTR (Kannikatti 750 m, Sengaltheri 1000 m, and Kakachi 1250 m) from June 1996 to August 1999 as part of an intensive ecological study of the Brown Palm Civet (Mudappa 2001).

Brown Palm Civet Paradoxurus jerdoni *photo-trapped in Sengaltheri, KMTR.*

Although climatically and biologically similar to KMTR, the rainforests of the Anamalai hills were fragmented between 1890 and 1930 due to establishment of commercial plantations. Most large fragments are within the Indira Gandhi Wildlife Sanctuary (IGWS, 987 km², 10°12'–35'N, 76°49'E–77°24'E, Fig. 1), but around 35 fragments (0.3–300 ha) are on private lands on the Valparai plateau, a 220 km² area dominated by plantations of tea, coffee, *Eucalyptus*, and cardamom (Mudappa & Raman in press). After independence (1947), many reservoirs were constructed and a network of roads established in this region, which further fragmented the landscape. However, even the relatively small fragments on private lands continue to harbour many endemic and endangered species of plants and animals and act as habitat facilitating movement of wide-ranging taxa (Muthuramkumar *et al*. 2006, Mudappa & Raman in press). The fragments within the landscape of plantations have a high conservation value, probably enhanced by their proximity to the surrounding large area of protected forests containing significant wildlife populations (Kumar *et al.* 2002, Raman 2006, Fig. 1).

Small carnivore surveys

The small carnivores in KMTR and Anamalai hills were surveyed using a combination of methods targeting nocturnal/crepuscular species as used in other studies (Zielinski and Kucera 1995, Duckworth 1998, Foresman and Pearson 1998, Silveira *et al*. 2003): a) track plots, b) camera-traps, and c) spot-lighting walks and night drives. Within KMTR, three intensive sites (Kannikatti, Kakachi, Sengaltheri; 600–1400 m asl) were surveyed. In the Anamalai hills, ten forest fragments of varying sizes (11–2600 ha) and disturbance levels (based on habitat degradation due to human activities, Muthuramkumar *et al.* 2006) within the same altitudinal range of mid-elevation tropical wet evergreen forest were sampled between January and May 2000 (Table 1). Survey stations within each site were located by walking a random number of paces in different directions to locate the first station along animal trails or streams through forest with subsequent stations placed at intervals of no less than 250 m.

Track plots were laid by clearing the leaf litter from the forest floor in an area of about 1 m × 0.75 m. Fine sieved soil was sprinkled over this plot, and a combination of baits (banana, dry fish/meat scraps) was placed on it. In KMTR, track plots were set for two successive nights at each station and checked in the mornings. Data from both nights were used as there was no significant difference in small carnivore visitation rate between the first and second night ($\chi^2 = 0.96$, *d.f.* = 1, $P > 0.25$) suggesting that baiting on the first night did not increase visitation rate on the second night. In KMTR, track plots were laid only in Sengaltheri at altitudes comparable to the sites in the Anamalai hills (600 to 1,400 m). In the Anamalai hills, for logistical reasons, track plots were run for only one night in each station and checked the following morning. The number of track plots laid was greater in larger fragments in order to distribute survey effort over a larger area in these fragments (Table 1). The tracks on the plots were distinguished as those of 1) Brown Palm Civet, if they were plantigrade prints with five digits clearly visible, or 2) other small carnivore (Small Indian Civet, Brown Mongoose, or others) based on the size and shape of the prints and if they had four digits and occasionally claw marks. This track identification protocol was unambiguous and based

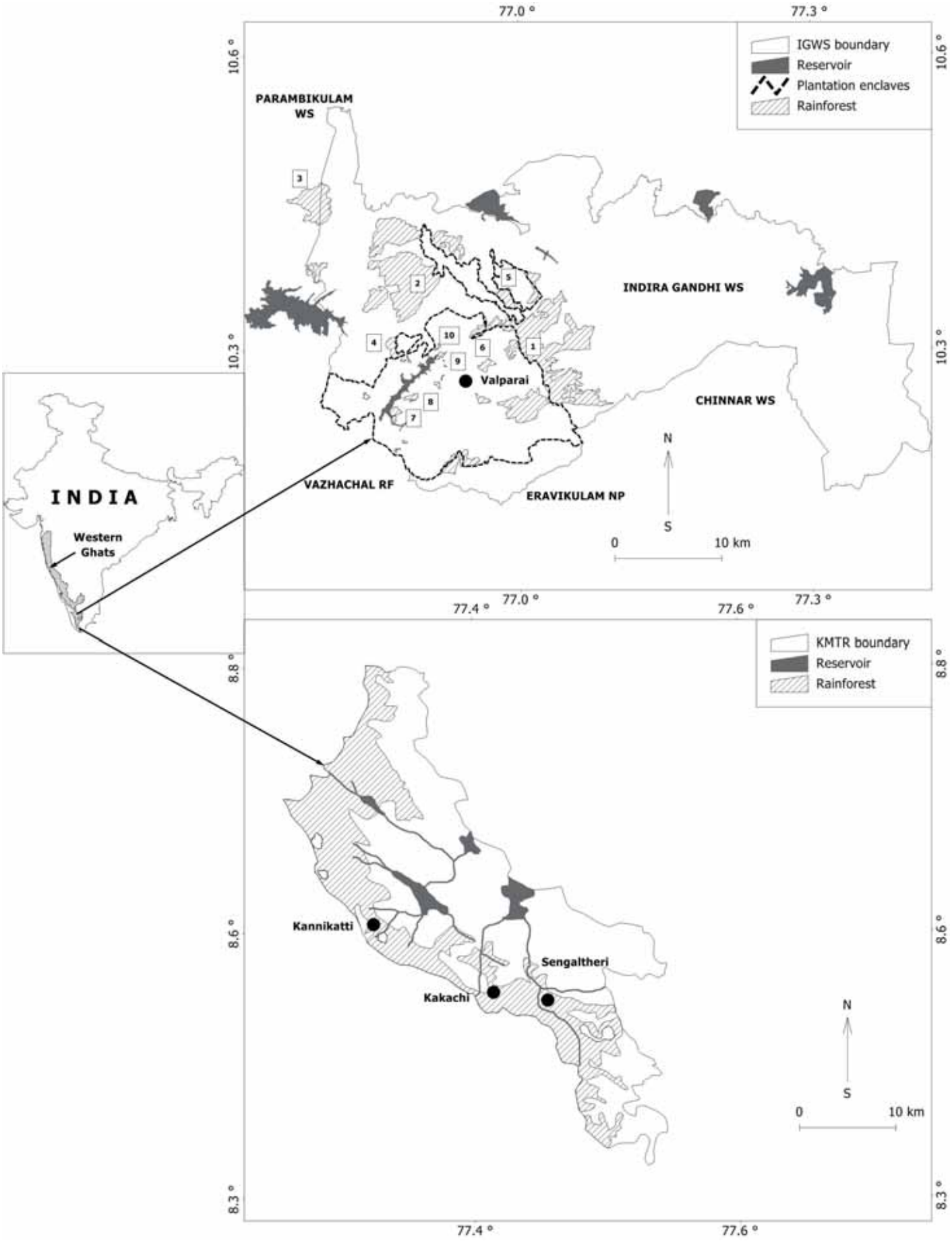

Fig. 1. Kalakad–Mundanthurai Tiger Reserve (bottom) showing the three study sites and distribution of contiguous rainforest and Indira Gandhi Wildlife Sanctuary in the Anamalai hills (top) showing the enclave of private plantations and rainforest fragments. The numbers correspond to the study fragments listed in Table 1.

Table 1. List of sites sampled in Kalakad–Mundanthurai Tiger Reserve (KMTR) and in the Anamalai hills, their attributes, and sampling effort in each (size class in parentheses: C – contiguous rainforest, VL – very large, L – large, M – medium, and S – small).

No.	Site	Area (ha)	Altitude (m)	Matrix*	Disturbance level	Camera-trap nights	Track plot nights
Kalakad–Mundanthurai Tiger Reserve							
1	Kakachi	(C)	1250	WEF, T	Low	19	-
2	Sengaltheri	(C)	1000	WEF, DD	Low	59	177
3	Kannikatti	(C)	750	WEF	Low	34	-
Anamalai Hills							
1	Akkamalai	2600 (VL)	1250-1500	T, G, SF	Low	15	60
2	Varagaliar	2000 (VL)	650-800	DD	Low	15	20
3	Karian Shola	500 (L)	750	B, DD	Low	10	30
4	Manamboli	250 (L)	800	T, C, DD	Low	10	30
5	Andiparai	200 (L)	1250	T, SF	Medium	10	30
6	Puthuthottam	92 (M)	1000	T, C, H, E	High	10	30
7	Pannimade	67 (M)	1100	C, T, R	Low	5	20
8	Korangumudi	50 (M)	1000	C, T, H, R	High	10	30
9	Tata Finlay	32 (S)	1000	C, T, E, H, R	High	5	25
10	Varattuparai	11 (S)	1100	T, C, SF, R	High	5	20

*T – tea plantation, G – grasslands, SF – secondary forests, DD – dry deciduous forest, C – coffee plantation, B – bamboo, R – reservoir, H – human habitation, E – eucalyptus plantation, WEF – wet evergreen forest

on standards obtained from track plots with camera traps (or live traps for radio-telemetry study) where species identification could be confirmed.

Camera-traps consisted of fixed-focus 32 mm Yashica cameras (with electronic shutter release, flash, and auto-winder) connected to pressure pads (Mudappa 1998). They were placed a minimum of 250 m from each other on existing forest trails or near streams. The pressure pad was placed on the ground and covered with a thin layer of soil and baited with banana, meat scraps, and occasionally dry fish or wild fruits. Traps were checked every morning, and the frame number, presence of tracks, use of bait, and any other indication of a small carnivore or other animal's visit were recorded. In KMTR, a camera-trap was run for a period of one to five nights at each station; however, for comparisons with camera-trap data from fragments in the Anamalai hills only data from the first night were used. This was because in the Anamalai hills each camera-trap was set at a new station every night in order to maximise the area sampled. Camera-trapping effort also varied in accordance with the size of the fragments in the Anamalai hills (Table 1).

Night walks were carried out in continuous rainforests of KMTR and within fragments in the Anamalai hills. Each night walk averaged 1.5 km in length and was covered in about one hour and ten minutes. The understorey and the canopy were scanned and searched for eye-shine or movements using spotlights (Novino 4-celled flashlight and Britelite Submersible Pro 5000 Series flashlight). Night drives were carried out to sample two contrasting landscapes: the Kakachi route in KMTR had a 34 km² plantation enclave surrounded by rainforests, while the Anamalai routes went through large expanses (c. 220 km²) of plantations with embedded rainforest fragments. All sightings of animals and variables such as habitat type and distance to the nearest rainforest were also noted.

Habitat structure measurement

Total tree and Brown Palm Civet food-tree densities and basal area were estimated using the point-centred quarter (PCQ) method (Krebs 1989) both in KMTR (n = 168 PCQ plots) and all the rainforest fragments (n = 190 PCQ plots, between 10 and 30 plots relative to area of fragment as in the case of survey stations mentioned above), except Varagaliar in the Anamalai hills. For Varagaliar, tree and food-tree densities, and basal area were derived from Ayyappan and Parthasarathy (1999). Habitat structural variables such as canopy height, canopy cover, and shrub density were estimated from measurements taken at 25 points within each study site, spaced at intervals of 50 m. Canopy height was measured using a clinometer or a range finder, canopy cover was measured using a spherical densiometer, and shrub density was estimated by counting the number of woody stems (< 10 cm in girth and ≥ 30 cm height) within 2 m radius plots at each of these 25 points. Area of fragments was estimated from digitised maps of the study sites.

Data analyses

Disturbance levels were assessed in the ten study fragments using habitat structure and a combination of 17 parameters such as presence of people, livestock, trails, and tree-cutting signs, as described in Muthuramkumar *et al*. (2006). The fragments were pooled into size classes for analyses as (1) small, ≤ 50 ha; (2) medium, 51–100 ha; (3) large, 101–1000 ha; and (4) very large, > 1000 ha.

The main index of abundance used in this paper is the success rates in track plots and camera-traps. For cryptic and nocturnal species such as small carnivores, such indices are frequently used to understand trends and patterns of variation across sites (Stander 1998, Carbone *et al*. 2002), until population sizes can be estimated using suitable methods (Jennelle *et al*. 2002, MacKenzie *et al*. 2005). Small carnivore visitation success rate was calculated as the percentage of successful track plot or camera-trap nights. A track plot or camera trap station was considered successful only if at least one track of a small carnivore was observed or a photograph obtained. Multiple tracks or pictures of the same species category on the same night at a station were taken as a single incidence. For analysis of track plot data, the two species categories considered are Brown Palm Civet and other carnivores, as indicated earlier. Success rates between the contiguous forests of KMTR and the rainforest fragments in the Anamalai hills and

among fragment size and disturbance classes were compared using chi-square tests (Siegel & Castellan 1988). Track plots and camera-traps were 'passive' sampling techniques that were not influenced by observer or visibility biases related to habitat structure or density of vegetation in the sampling sites. This allows the unbiased comparison of success rates of particular species between sites as well as the relative abundance of species (percentage of visits of one species relative to total visits recorded) among sites. Although this relative success rate may not reflect the true ratio of abundances of various species (see Discussion), differences in relative success rates among sites are likely to be representative of changes in the underlying ratios.

In addition to success rates, encounter rates from direct sightings along night walks and drives are also provided. These, however, are likely to be influenced by detectability biases related to vegetation structure and need to be treated with caution. Hunting pressures were negligible in the study areas (D. Mudappa personal observations) and therefore unlikely to have influenced detectability. To examine differences in habitat characteristics between the contiguous rainforests in KMTR and the fragments in Anamalai hills, the Mann-Whitney U test was used (Siegel & Castellan 1988). For the Anamalai hills, success rates at each rainforest fragment were correlated with habitat and site variables, using Spearman rank correlations. Results were assessed as statistically significant at $P < 0.05$ and moderately significant at $P < 0.10$.

Results

Small carnivore surveys

Three species of nocturnal small carnivores were detected during the surveys in KMTR and the fragments in the Anamalai hills. Their occurrence and success rates in track plots and camera traps in the different sites is presented in Table 2. The overall small carnivore success rate of 48% in the 177 track plots (night 1 = 100, night 2 = 77) in Sengaltheri, KMTR, was significantly higher than the 32.2% (95 of 295 trap-nights) success rate in the fragments in the Anamalai hills ($\chi^2 = 11.73$, *d.f.* = 1, $P < 0.001$). The success rate in the Anamalai hills ranged between 8.0% in Tata Finlay, one of the small-sized (≤ 50 ha) fragments, to 46.7% in Korangumudi, a medium-sized (51–100 ha) fragment. In KMTR, 91% of the small carnivore visitation in track plots was by the Brown Palm Civet and other small carnivore tracks occurred rarely (9%, Fig. 2). In the rainforest fragments of the Anamalai hills, the Brown Palm Civet contributed to 50% ($n = 48$), and other small carnivores 50% ($n = 48$, Fig. 2). Success rate was higher in KMTR than in the Anamalai hills for both the Brown Palm Civet ($\chi^2 = 48.45$, *d.f.* = 1, $P < 0.001$) and for other small carnivores ($\chi^2 = 14.61$, *d.f.* = 1, $P < 0.001$).

Camera-trapping success rate in KMTR of small carnivores was 41.1%, with three species photo-trapped: Brown Palm Civet, Small Indian Civet, and Brown Mongoose. In both study areas, in and around the rainforest sites, Common Palm Civet *Paradoxurus hermaphroditus* does not occur and was neither photo-trapped nor sighted during the study period or subsequently till date. This species, the tracks of which might be confused with those of Brown Palm Civet, was recorded frequently only in drier deciduous forests at lower (< 800 m) elevations within these hills and never in the rainforests. In Sengaltheri and Kakachi, all three small carnivores were photo-trapped, and in Kannikatti only the Brown Palm Civet was photo-trapped. Kakachi had the highest trapping success of 73.7% ($n = 19$ trap-nights), followed by Sengaltheri with 42.4% ($n = 59$), and Kannikatti with 20.6% ($n = 34$; $\chi^2 = 14.29$, *d.f.* = 2, $P < 0.001$). Brown Palm Civet was photo-trapped on 37 nights, accounting for about 80.4% of the success, Small Indian Civet on seven nights (15.2%), and Brown Mongoose on two nights (4.4%, Fig. 2). The capture rate of Brown Palm Civet was significantly positively related to altitude, being 57.9% in Kakachi (1250 m), 32.2% in Sengaltheri (1000 m), and 20.6% in Kannikatti (750 m; $\chi^2 = 7.71$, *d.f.* = 2, $P = 0.021$).

Camera-trapping success in the rainforest fragments of the Anamalai hills was significantly lower than in KMTR, with a success rate of 16.8% ($n = 95$ trap-nights) as against 38.8% ($n = 49$, $\chi^2 = 8.45$, *d.f.* = 1, $P = 0.004$) on night 1 in KMTR, and 41.1% overall ($n = 112$, $\chi^2 = 14.38$, *d.f.* = 1, $P < 0.001$). However, even in the Anamalai hills, Brown Palm Civet was the most frequently photo-trapped small carnivore, contributing to 50% of the success (8 trap-nights), although lower than in KMTR (80.4%, Fig. 2). The capture rate of Brown Palm Civet was also significantly lower

Table 2. Success rates of small carnivore detections on track plots and camera traps in Kalakad–Mundanthurai Tiger Reserve (KMTR) and in the rainforest fragments in the Anamalai hills.

Site	Track plots (%)		Camera traps (%)		
	Brown Palm Civet	Other small carnivores	Brown Palm Civet	Small Indian Civet	Brown Mongoose
Kalakad–Mundanthurai Tiger Reserve			34.7		
Kakachi			57.9	10.5	5.3
Sengaltheri	45.8	4.5	32.2	8.5	1.7
Kannikatti			20.6	0	0
Anamalai hills			8.4		
Akkamalai	13.3	26.7	0	0	20
Varagaliar	5	10	0	0	0
Karian Shola	6.7	20	10	0	10
Manamboli	20	20	0	10	0
Andiparai	26.7	10	0	10	10
Puthuthottam	20	13.3	40	0	0
Pannimade	40	5	40	0	0
Korangumudi	23.3	23.3	10	0	0
Tata Finlay	4	4	0	0	0
Varattuparai	10	5	0	0	20

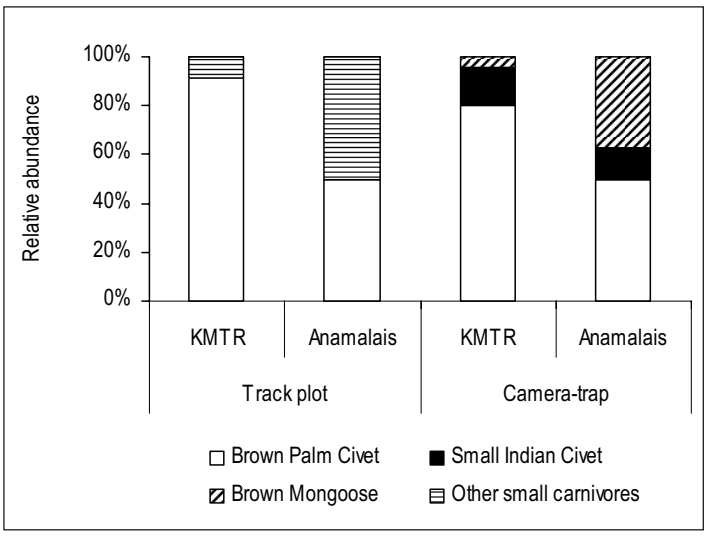

Fig. 2. Relative abundance of small carnivores using track plots and camera-traps—comparisons between the contiguous rainforests of Kalakad–Mundanthurai Tiger Reserve (KMTR) and the fragmented rainforests of the Anamalai hills.

in the Anamalai hills (8.42%) than in KMTR on night 1 (34.7%, $\chi^2 = 18.31$, *d.f.* = 1, $P < 0.001$). In the Anamalai hills, Brown Mongoose was the second most frequently photo-trapped species of small carnivore (37.5%), followed by Small Indian Civet (12.5%, Fig. 2). Although Brown Mongoose was photo-trapped a greater number of times in the Anamalai hills than in KMTR, and Small Indian Civet fewer times, the differences were not statistically significant ($\chi^2 = 2.84$, *d.f.* = 1, $P = 0.09$, and 2.12, *d.f.* = 1, $P = 0.15$, respectively). The camera-trapping success was highest in Puthuthottam and Pannimade, both medium-sized fragments. There were no photo-captures of small carnivores in Varagaliar, the largest fragment of those at low elevation, and in Tata Finlay, one of the small fragments.

Twenty-five night walks (totalling 32 hr 35 min) on forest trails were carried out in Kakachi, Sengaltheri, and Kannikatti in KMTR between November 1996 and September 1997. Three Brown Palm Civets were sighted resulting in an encounter rate of 0.09 animals/hr. In the Anamalai hills, 12 night walks were carried out (13 hr 10 min) in seven rainforest fragments. Time spent in a walk ranged between 30 and 140 minutes, depending on the size of the fragment. Four Brown Palm Civets were seen during these night walks, resulting in an encounter rate of 0.30 animals/hr. The Brown Palm Civets were sighted in one large (Andiparai) and one very large (Akkamalai) fragment.

During seven night drives in Kakachi in KMTR (100 km in 5 hr 15 min), one Brown Palm Civet, seven Small Indian Civets, and one Leopard Cat were seen, giving an encounter rate of 1.7 animals/hr of drive or 0.09 animals/km. We covered a distance of 281.5 km over 11 hr 40 min in 19 night drives in the Anamalai hills. During these drives, one Brown Palm Civet (at a rainforest fragment edge) and two Small Indian Civets (at tea estate edges) were sighted, giving an encounter rate of 0.26 animals/hr or 0.01 animals/km.

Determinants of small carnivore occurrences in rainforests

With the exception of the very large fragment, Akkamalai, and the large Karian Shola fragment, the tree densities of all the other rainforest fragments in the Anamalai hills were lower than any of the rainforest sites in KMTR (Table 3). However, among the habitat variables, only Brown Palm Civet food-tree density was significantly higher in the sites in KMTR as compared with the rainforest fragments in the Anamalai hills (Mann-Whitney *U* test, $Z = -2.54$, $P = 0.007$, Table 3). Among fragments, only tree density was significantly correlated to area ($r_s = 0.721$, $n = 8$, $P < 0.05$). None of the other variables were, however, significantly correlated to either fragment area or altitude. Basal area in the forest fragments was significantly positively correlated to both tree and food-tree densities ($r_s = 0.709$ and 0.697, respectively, $n = 10$, $P < 0.05$). Canopy cover, as expected, was significantly correlated to tree density and basal area ($r_s = 0.782$ and 0.685, respectively, $n = 10$, $P < 0.05$). No other significant correlations were found among habitat structure parameters.

The visitation success rate of Small Indian Civet in the track plots in the Anamalai hills was weakly correlated to area of the fragments ($r_s = 0.612$, $n = 10$, $P = 0.06$), while that of Brown Palm Civet was positively correlated with altitude ($r_s = 0.624$, $n = 10$, $P = 0.054$), the latter similar to the pattern observed in the contiguous rainforests of KMTR. None of the other small carnivore success rates was significantly correlated to any of the habitat variables.

There were no significant differences (χ^2 analyses) among fragments of varying size classes or disturbance levels in the success rates of either individual species or of all small carnivores pooled, in both track plot or camera-trap method. The only exception was that track plot success of Brown Palm Civet was significantly different between sites of varying size classes ($\chi^2 = 11.35$, *d.f.* = 3, $P < 0.01$) with success being highest in medium-sized fragments (26.3%) as compared with small (6.7%), large (17.8%), and very large (10%) fragments.

Discussion

Despite the limited data-set available, this study provides a first documentation of the responses of cryptic nocturnal small carnivores to rainforest fragmentation in south Asia by using a combination of methods in two contrasting landscapes. The use of similar methods in both landscapes allows comparison of overall capture rates as well as variation in inferred relative abundance for each species across sites; however, the actual relative abundance of a given species, compared with the other species, may be at variance with the real ratio, because different species may vary in their attraction to the trap stations, but any such differences could not be assessed.

The higher success rates in track plots (48%) and camera-trapping (41.1%) in KMTR than in the Anamalai hills (32.2% success in track plots and 16.8% in camera-traps) indicate higher abundances of small carnivores in relatively undisturbed contiguous rainforests. This is unlikely to be merely a consequence of greater avoidance of trap stations in the Anamalai hills due to human use of fragments, as success rates were low even in large fragments within the protected area that were not visited or disturbed by people. Greater success rate in contiguous rainforests was mainly due to visitations by Brown Palm Civet, a species that was previously considered rare (Ashraf *et al*. 1993). Brown Palm Civet contributed to only half the success in the Anamalai hills, in contrast to more than three-fourths in KMTR. Thus, although the terrestrial and arboreal small carnivores persist in the fragmented landscape, they occur in altered relative abundances. Encounter rates appeared to be higher in the rainforest fragments than in con-

tinuous forest only in night walks. This cannot be concluded to indicate a genuine difference in densities, and was surely an artefact because of poorer visibility due to the much denser foliage and forest stand in KMTR than in the more degraded fragments in the Anamalai hills. Spotlighting was not an effective method of sampling rainforest small carnivores as encounter rates were very low, as noted in other studies (Duckworth 1998, Mudappa 1998).

Another factor influencing the distribution of Brown Palm Civet was altitude, with the species being more common at altitudes above 900 m. In addition, the higher capture rates indicating higher abundances in KMTR are probably sustained by the higher food plant species densities in the relatively undisturbed rainforests, particularly species such as *Palaquium ellipticum, Holigarna nigra, Elaeocarpus* spp*., Ficus* spp*., Acronychia pedunculata,* and *Gnetum ula* (Mudappa 2001). Within the fragments of the Anamalai hills, however, food-tree density did not show a direct relationship with the success rates of Brown Palm Civet. The medium-sized fragments had greater success rates, probably because they had (1) some coffee plants (the fruits of which are consumed by civets) in the understorey, and (2) shade-coffee plantations in the surrounding matrix that retained some native, rainforest species as shade trees (including fruit species such as *Ficus* spp. and *Artocarpus heterophyllus*). These fragment characteristics increased the effective food and habitat available to civets. However, these are highly disturbed fragments on private lands, whose long-term survival is threatened. Although two small fragments and one large fragment also adjoined shade-coffee plantations, their influence on civets may have been suppressed by other factors such as smaller area and lower altitude of the fragments.

Forest fragmentation and disturbances such as logging have been shown to have varying effects on different groups of mammals. Species such as tree squirrels, for instance, may increase in abundance (Johns 1988, Koprowski 2005). Similar to results of studies on the impact of habitat disturbances on other mammals (Johns 1988, Wilkie & Finn 1990, Oehler & Litvaitis 1996), there seemed to be a relative increase or no significant change in the abundance of more terrestrial and more omnivorous-carnivorous species like the mongooses and Small Indian Civet in fragments. Within-patch habitat characteristics did not predict the occurrence of these small carnivores, instead these species may remain relatively unaffected by fragmentation because of their ability to use modified habitats in the surrounding landscape matrix (Leighton & Leighton 1983, Laurance 1991). As observed here, earlier work has shown that disturbed habitat fragments are susceptible to invasions by more widespread and generalist species at the cost of restricted endemics and specialists, altering the composition of the community (Oehler & Litvaitis 1996). The changes in relative abundance, favouring common and widespread omnivorous or insectivorous species like all the mongooses and Small Indian Civet, may also be due to the increase in abundance of small mammal prey in the fragments and probable increase in leaf-litter arthropod abundance along edges and in disturbed fragments (Didham 1997, Malcolm 1997, Ray & Sunquist 2001). Since there is understorey cover in the surrounding plantation matrix, these more ground-dwelling species are least likely to be affected by fragmentation (Wilkie & Finn 1990, Laurance 1991).

In Borneo and Malaysia, many species of civets are known to persist in selectively logged forests, although in significantly lower abundances with the predominantly carnivorous (insectivorous) subfamilies of Viverrinae and Hemigalinae being most affected (Heydon & Bulloh 1996, Colón 2002). In contrast, in the present study, the arboreal and predominantly frugivorous Brown Palm Civet suffers from fragmentation probably because of its inability to survive in a matrix of tea plantations devoid of continuous tree cover and sufficient diversity of fruit resources (Mudappa 2001). With the exception of fragments with coffee in the understorey, most others not only have very low food-tree densities, but also harbour many exotics that bear fruits not usually eaten by the civets. This is similar to studies on primates that have also shown highly frugivorous and folivorous primates to be affected by major reduction in food species due to logging and associated disturbances (Johns 1988, Struhsaker 1997, but also see Fimbel 1994). Moreover, in order to meet their daily resource requirements, civets may have to range over a wider area in fragments than in undisturbed rainforests (a maximum of about 60 ha in undisturbed rainforests, Mudappa 2001). Most of the fragments are less than 100 ha in area, and this could explain the lower abundances of this species. The persistence of civets in fragments also needs to be evaluated in future studies in relation to their ability to use surrounding matrix habitats and other threats such as vehicular colli-

Table 3. Habitat structure measurements of different sites in the contiguous rainforests of KMTR and in the rainforest fragments in the Anamalai hills (SE in parentheses).

Sites	Tree density (number/ha)	Food-tree density (number/ha)	Basal area (m^2/ha)	Canopy height (m)	Canopy cover (%)	Shrub density (number/12.57 m^2)
Kalakad–Mundanthurai Tiger Reserve						
Kakachi	738 (4.8)	241	65.10	23.83 (0.7)	93.68 (0.8)	20.77 (2.4)
Sengaltheri	680 (1.9)	280	77.78	20.92 (0.9)	93.84 (0.9)	19.26 (2.7)
Kannikatti	624 (4.0)	244	70.90	24.38 (1.2)	94.66 (0.6)	15.66 (2.0)
Anamalai hills						
Akkamalai	697 (5.0)	209	52.49	22.65 (1.4)	97.70 (0.5)	10.20 (0.6)
Varagaliar	446	82	36.26	28.56 (1.4)	94.68 (0.7)	15.76 (1.7)
Karian Shola	755 (7.6)	181	95.86	27.00 (0.7)	98.20 (0.2)	23.84 (2.4)
Manamboli	582 (5.8)	175	114.41	24.54 (1.1)	94.96 (1.4)	11.64 (1.1)
Andiparai	431 (4.4)	169	84.49	22.66 (1.8)	96.24 (0.7)	26.32 (2.9)
Puthuthottam	239 (2.4)	107	52.49	22.70 (1.9)	89.00 (1.3)	7.88 (0.8)
Pannimade	534 (13.7)	187	47.48	22.43 (1.8)	92.48 (0.8)	34.16 (3.0)
Korangumudi	196 (1.9)	84	31.25	20.74 (2.1)	68.24 (3.2)	8.83 (1.2)
Tata Finlay	331 (5.6)	116	40.31	31.32 (1.9)	96.32 (1.2)	11.04 (0.9)
Varattuparai	295 (7.6)	103	33.47	11.11 (2.2)	95.65 (0.9)	3.73 (0.8)

sions along roads.

Moreover, techniques have been recently developed to enable estimation of the proportion of area of occupied (PAO), or the probability that a site is occupied, by a species of interest based on presence-absence surveys (MacKenzie *et al*. 2002, 2005). Future studies, particularly in areas that are being surveyed for the first time, could be designed so as to enable the estimation of patch occupancy and detection probability of the species of interest at the landscape level.

Conservation implications

The Kalakad–Mundanthurai Tiger Reserve with its large tract of relatively undisturbed rainforests deserves recognition as one of the most significant areas for the long-term conservation of small carnivores in the Western Ghats, particularly the endemic Brown Palm Civet, an important frugivore and seed disperser in these rainforests (Mudappa 2001). In a fragmented landscape, fragments adjoining shade-coffee plantations appear to support higher abundances of Brown Palm Civets than those remote from shade-coffee, thereby indicating such land use to be less ecologically damaging and consistent with broader conservation goals than plantations such as tea. The study indicates three major management measures that would aid in the conservation of small carnivores in the region. First, there is a need to identify and include even isolated and disturbed rainforest fragments on private lands within the management purview of endangered habitats and species, as most of these still contain endemic small carnivore populations. Second, restoration of highly degraded rainforests by planting of food plant species and maintenance of shade-coffee plantations with native shade trees will augment habitat quality and help sustain populations of endemics such as the frugivorous Brown Palm Civet at the landscape level. Finally, to discern trends in small carnivore populations in these areas and assess the success of implemented management measures there is a need for regular and systematic monitoring, using suitable field methods and recent advances in quantitatively rigorous study design, monitoring, and analysis protocols (Pollock *et al*. 2002, MacKenzie & Nichols 2004, MacKenzie *et al*. 2005). These management measures should ideally supplement protection of larger tracts of forests within designated wildlife preserves, and the development of a better information base through additional surveys and monitoring of the status of small carnivores in the region.

Although the persistence of small carnivore species following habitat fragmentation bodes well for their conservation given large areas of protected forest and relatively low pressures from hunting and land-use conversion even on private land as in the Anamalai hills, future research on some key aspects will help reinforce this assessment. These include: (1) the role of the various plantations and land-use practices in the long-term persistence of small carnivores, particularly endemic species such as the Brown Palm Civet and Nilgiri Marten, (2) the role of landscape connectivity and protected forests in dispersal and maintenance of species' populations in the fragments, and (3) to determine the roles of fragments and plantations in the source-sink dynamics at the landscape level for certain species of interest.

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