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Edge effects on terrestrial arthropods in primary, tropical, sub-montane forest and tea plantations of the Usambara Mountains, Amani, Tanzania

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Abstract: This study was conducted in Amani Nature Reserve, East Usambara Mountains, Tanzania and considered the effect of prominent forest/tea boundaries on species abundance, diversity and similarity of terrestrial invertebrates. Sampling involved pitfall traps planted along transects that crossed the two habitats separated by a clearly defined boundary or 'edge'. A total of 3806 arthropods was collected and assigned to 161 morpho-types, with the exception of 621 specimens (16 %) of Collembola, Blattodea, Gryllidae and Rhaphidophoridae. Of 80 traps, two collected 1751 individuals (46 % of total arthropods sampled) of a single species of army ant (*Dorylus* sp.). Both abundance and diversity were significantly higher when crossing from forest habitat to the edge. Decreases in mean abundance and diversity by 40 % and 50 % respectively were evident when moving from the forest habitat and edge to the tea habitat, whilst similarity in species composition showed a greater rate of decline when moving from the forest habitat to tea than in the opposite direction. It is evident from our preliminary study that even over such short distances (maximum of 100 m), edge effects on biotic diversity and abundance are apparent. In an already heavily fragmented, ancient, forest habitat where patches are continually being created, it is important to consider the extent to which further fragmentation may potentially impact upon the endemic floral and faunal community.

Keywords: Arthropoda, terrestrial, pit fall trap, diversity, similarity, Usambara Mountains, Tanzania, Africa

Introduction

The tropical submontane forest of the Eastern Arc mountains (north-east Tanzania) represents an area of high ecological diversity facilitated through isolation over geological time and fragmentation. Over 2000 plant species (of which 25 % are endemic) have been documented here (RODGERS & HOMEWOOD 1982), such that it has been considered one of the 24 globally most important forest biodiversity ‘hotspots’. One protected area is the East Usambara Mountains, which represents just one fragment of the Eastern Arc mountain chain. This is an area of enhanced endemism promoted by a moist climate (40 km from the Indian Ocean); however the proportion of forest cover has declined since the 1900’s from 80 % to 50 % cover today (MOREAU 1935) as a result of clearances for crop agriculture, commercial timber and tea estates.

Large-scale coffee plantations established during German colonialism were converted to tea plantations following British rule in the 1950’s (RODGERS & HOMEWOOD 1982), and despite a halt to major commercial logging in the late 1980’s, these still remain as dominant monoculture patches amongst the continually declining area of primary forest landscape (covering an area of 8380 ha). To reduce such dominance, a number of management policies have been introduced to plantation owners within the Amani Nature Reserve, aimed primarily at minimising erosion risks and controlling plantation expansion.

The widespread forest - tea habitat boundaries within the Amani Nature Reserve present an opportunity for so-called ‘edge effects’ to be imposed upon existing floral and faunal communities. Such effects are set up within a landscape where native, remnant vegetation lies adjacent to patches of managed land, resulting in a discontinuity in abiotic and biotic factors along an environmental gradient. At these ‘edges’ changes in physical parameters such as temperature, moisture, wind and soil characteristics (NEWMARK 2001), and biological factors such as increased predation (CARLSON & HARTMAN 2001) and niche availability (DONOVAN et al. 1997), affect the mobility and consequent ‘permeability’ of an organism through edges of varying boundary types (SAUNDERS et al. 1991). Consequently, such an edge could affect the ecology of the floral and faunal community present to varying degrees, and must be considered when understanding the impact of habitat fragmentation and patch isolation on species mobility and extinction (TURNER 1996, DIDHAM et al. 1998).

We aim to investigate the effect of a changing environmental gradient, from primary, tropical, sub-montane forest to monoculture tea plantation, on species abundance, diversity and composition of terrestrial invertebrates. We hypothesise that the number of individuals and species will significantly differ between the two habitats, with enhanced abundance and diversity expected particularly at the edge where the two habitat boundaries meet, as a consequence of convergence between invertebrate communities present at each habitat.

Material and methods

Site. This study was carried out over two weeks during the dry season in September 2003, in Amani Nature Reserve, Tanzania (836 m a.s.l.; 5°06’05”S/38°37’44.4”E). The sites selected lie within the continuous forested fragment of the East Usambara Mountains, adjacent to Derema Forest. Our study area involved the assessment of two contrasting habitats: primary, tropical, sub-montane forest of the Eastern Usambaras, and tea monoculture plantation, established approximately 40–50 years ago and receiving regular, bimonthly pesticide and leaf-clipping management every two to three years.

Physical parameters. For each of the four transects, light intensity (using Extech™ Light Meters, cross-calibrated), temperature (degrees Celsius) and Relative Humidity (% RH) readings were taken at 10 m intervals from the edge (-40, -30, -20, -10, 0 (forest-tea edge), +10, +20, +30, +40 m).

Experimental design. Four adjacent yet independent sites, each owning a clear boundary between continuous forest and tea plantation, were selected. Each boundary chosen were of a minimum of 100 m in length. For each of the boundaries assessed, sampling was carried out at four transects extending 40 m into both forest and tea habitat from the boundary edge. These transects were set approximately 20 m apart along the length of the boundary. At five distances (10 m and 40 m into each habitat type, and at the edge between the two habitat types; Table 1) two pitfall traps (approximately 215 ml in volume) containing a dilute soap solution were set. Traps were left for three to four days before collection. Samples were sieved and bottled in situ prior to cleaning, sorting, preservation and identification in the laboratory.

Table 1: Sampling design: location of pitfall traps at four transects at each site boundary.

Transect	(Forest)		Edge		(Tea)
1	-40 m	-10 m	0 m	10 m	40 m
2	-40 m	-10 m	0 m	10 m	40 m
3	-40 m	-10 m	0 m	10 m	40 m
4	-40 m	-10 m	0 m	10 m	40 m

All arthropods collected in the pitfall traps were sorted to major groups and counted. Subsequently all arthropods excluding Collembola, Blattodea and Gryllidae (Ensifera) were assigned to morpho-types. Ants were identified to genus level (HÖLLDOBLER & WILSON 1990) and subsequently assigned to morpho-types. Faunal overlap between sites was measured using Sørensen's Index of Similarity.

Results

Physical Parameters

Mean temperature ranged from 21.5 ± 0.2º C (standard error) in the forest habitat, increasing to 22.4 ± 0.3º C at the edge, and to 24.3 ± 0.5º C within the tea plantation. An increase in temperature by one to two degrees is obvious at the edge, this trend being consistent throughout the sites sampled.

Low light intensity within the forest habitat was consistent between the four sites measured, with the overall mean intensity changing from 11.2 ± 2 Lux at 40 m into the forest, to 93.8 ± 21.5 Lux at the edge, and 295.4 ± 73.3 Lux at 40 m within the tea plantation. Light intensity within the tea plantation was up to 60 times higher than the forest readings.

Mean Relative Humidity measurements per site showed greater variation within the forest (ranging from 62.0 to 72.5 % RH) than within the tea habitat (ranging from 64.8 to 69.8 % RH).

Table 2: Number of individuals of arthropods collected in each 16 pairs of pitfall traps 40 m and 10 m in the forest (F 40, F 10), at the edge (E 0), 10 m and 40 m in the tea plantation (T 10, T 40); no. of morpho-types (~ species) per row, n mt: not assigned to morpho-types.

	Habitat **Distance (m)**	**F** **40**	**F** **10**	**E** **0**	**T** **10**	**T** **40**	**no.** **spec.**
Arachnida							
Araneae	Dysteridae	3	6	3	3	1	2
	Lycosidae	6	14	21	9	22	14
	Salticidae	6	7	7	3	-	6
	Thomasidae	-	-	2	-	-	1
	other taxa	4	1	7	4	1	11
Opiliones		2	2	2	-	5	6
Acari	Ixodidae	-	-	1	-	-	1
	other taxa	5	5	3	6	1	7
Crustacea							
Amphipoda		18	2	10	8	6	1
Isopoda		11	16	14	6	6	4
Chilopoda		3	1	6	2	1	4
Diplopoda		4	2	3	2	3	4
Insecta							
Collembola		88	122	89	100	56	n. mt
Archaeognatha	Machilidae	1	1	2	-	-	1
Dermaptera		5	3	1	2	-	5
Isoptera		-	-	1	2	-	3
Blattodea		1	-	9	4	5	n. mt
Caelifera	Acrididae	-	-	1	-	-	1
	Tetrigidae	2	4	4	-	4	1
Ensifera	Gryllidae	27	37	33	25	25	n. mt
Heteroptera	Anthocoridae	1	1	1	-	-	2
	Aradidae	1	-	-	-	-	1
	Cydnidae	1	1	1	3	-	3
	Lygaeidae	-	1	1	-	-	1
	Nabidae	-	-	1	-	-	1
	Reduviidae	-	-	-	1	-	1

	Habitat Distance (m)	F 40	F 10	E 0	T 10	T 40	no. spec.
Homoptera	Cercopidae	18	6	5	1	-	5
	Cicadellidae	1	-	7	-	-	3
	Delphacidae	1	-	-	-	-	1
Coleoptera							
Byrrhidae		1	-	2	-	-	1
Carabidae	Carabinae	-	5	-	-	-	2
	Harpalinae	-	1	-	-	1	1
	Nebriinae	-	-	2	-	-	1
	Perigoninae	1	-	1	-	-	2
	Pterostichinae	3	3	4	2	-	3
	Scaritinae	2	3	1	-	1	2
	Zabriinae	1	-	-	-	1	1
Chrysomelidae	*Longitarsus*	1	-	1	-	-	1
Curculionidae		-	1	-	1	2	3
Hydrophilidae	*Cercyon*	1	7	1	-	-	2
Lampyridae		1	1	1	-	-	1
Leiodidae		-	1	-	-	-	1
Nitidulidae		40	52	11	-	-	5
Scarabaeidae	*Ontophagus*	18	9	6	7	15	5
Staphylinidae	Aleocharinae	9	20	15	2	-	3
	Anotylinae	30	26	14	7	6	3
	Paederinae	1	3	1	-	-	2
	Piestinae	-	-	-	-	1	1
	Staphylininae	4	4	1	1	-	5
Tenebrionidae		-	2	-	-	-	1
Hymenoptera, Formicidae							
Dorylinae	*Dorylus*	1	-	1048	703	1	1
Formicinae	*Acropyga*	1	-	1	-	-	1
	Cataglyphis	1	-	1	1	-	3
	Lepisiota	1	-	75	-	-	3
	Polyrachis	-	-	1	-	-	1
Myrmicinae	*Cataulus*	-	-	1	1	-	1
	Pheidole	57	6	92	110	97	2
	Tetramorium	11	15	53	-	2	2

	Habitat Distance (m)	F 40	F 10	E 0	T 10	T 40	no. spec.
	Wasmannia	2	2	2	-	-	1
Ponerinae	*Centromyrmex*	3	1	2	-	3	2
	Odontomachus	8	7	4	4	1	1
	Dolioponera	1	2	-	1	1	1
	Pachycondyla	47	4	18	6	25	1
Sphecidae		2	14	8	-	-	5
No. of species (taxa assigned to morpho-types)		**80**	**77**	**82**	**49**	**38**	**161**
No. of individuals		**458**	**424**	**1605**	**1026**	**293**	**3806**

Table 3: Sørensen similarity indices between habitats 40 m, 10 m into the forest (F40, F10), edge (E), and 10 m, 40 m into the tea plantation (T10, T40).

site 1	F40	F10	E	T10		site 3	F40	F10	E	T10
F10	**0.39**			> **0.25**		F10	**0.40**			
E	**0.22**	**0.42**		> **0.35**		E	**0.29**	**0.32**		
T10	**0.18**	**0.24**	**0.15**			T10	**0.40**	**0.37**	**0.23**	
T40	**0.19**	**0.25**	**0.22**	**0.27**		T40	**0.33**	**0.20**	**0.24**	**0.29**
site 2	F40	F10	E	T10		site 4	F40	F10	E	T10
F10	**0.37**					F10	**0.43**			
E	**0.45**	**0.45**				E	**0.35**	**0.44**		
T10	**0.24**	**0.17**	**0.19**			T10	**0.37**	**0.24**	**0.33**	
T40	**0.19**	**0.37**	**0.34**	**0.41**		T40	**0.30**	**0.22**	**0.32**	**0.32**

Terrestrial arthropod assemblages

Abundance. A total of 3806 arthropods were sampled and identified from 80 pairs of pitfall traps left for four consecutive nights prior to collection (Table 2). The lack of significant difference in the number of individuals between transects per site allowed the data to be pooled (Two-way ANOVA; $F_{3.64} = 1.84$; $p = 0.15$; Fig. 1). 46 % of arthropods collected from two traps at transect four belonged to a single species of army ants (*Dorylus* sp.), found at edge and at 10 m into the tea plantation. Excluding the data from transects four, a significant decrease in arthropod abundance when going from the edge to the tea plantation could be found ($F_{4.45}$ = 3.6; p <0.01; Fig. 2).

There was almost a 50 % decrease in species abundance between samples collected at 40 m into the forest habitat and 40 m into the tea habitat. The greatest decline in abundance was found to occur between the edge and tea (+10m).

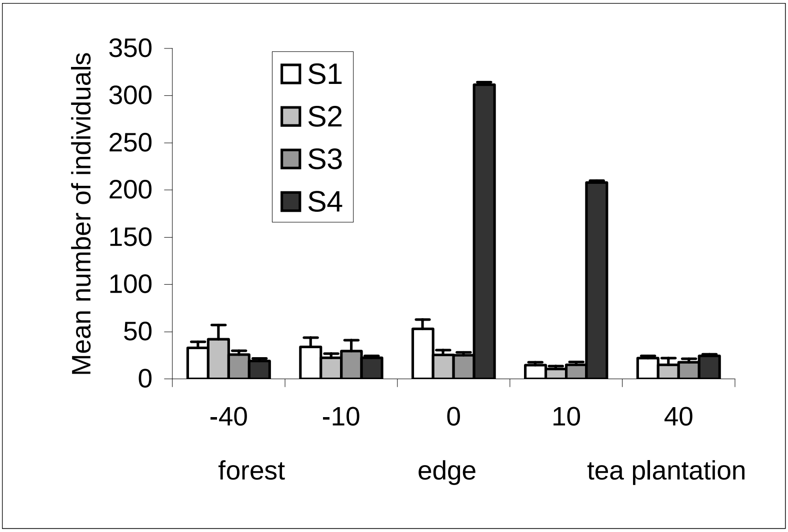

Fig. 1: Mean number of individuals per transect point for each of the four sites (S).

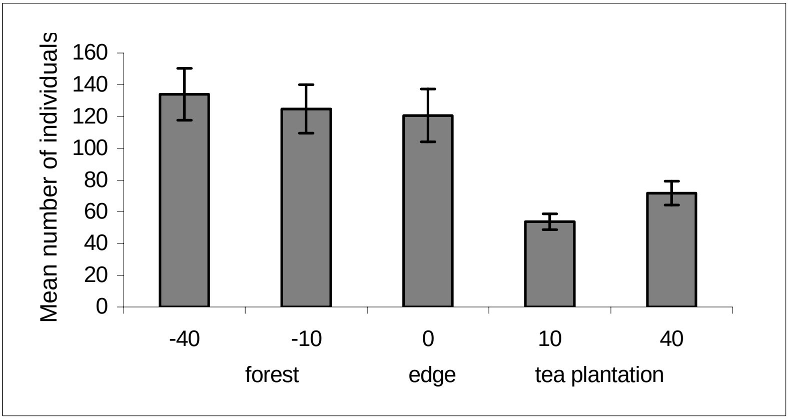

Fig. 2: Mean number of individuals per transect point (data of site 4 excluded).

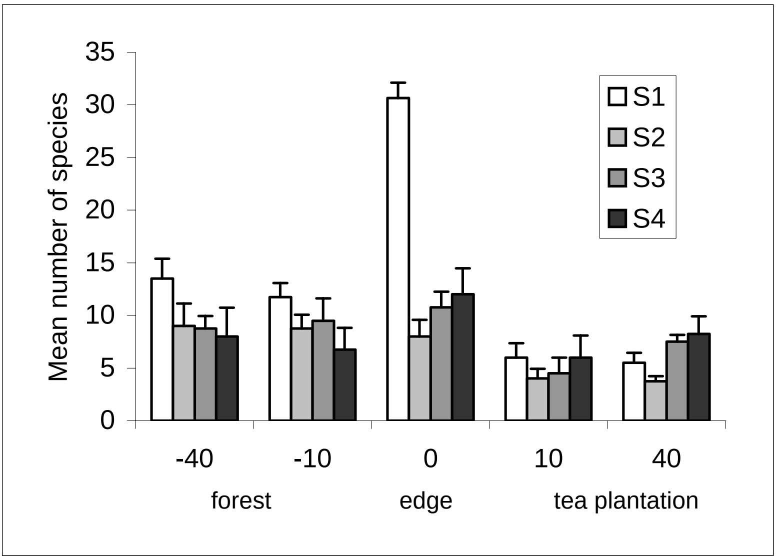

Fig. 3: Mean number of morpho-types (~species) point for each of the four sites (S).

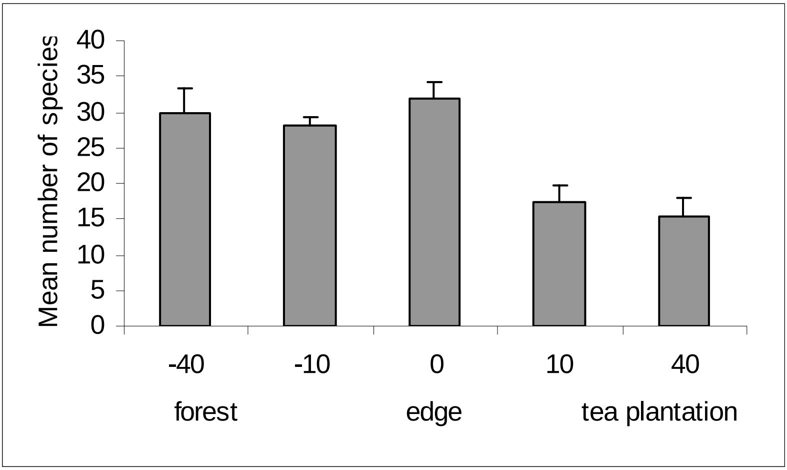

Fig. 4: Mean number of morpho-types (~ species) sampled when crossing habitats of forest via edge to tea per site (n=16, pairs of traps)

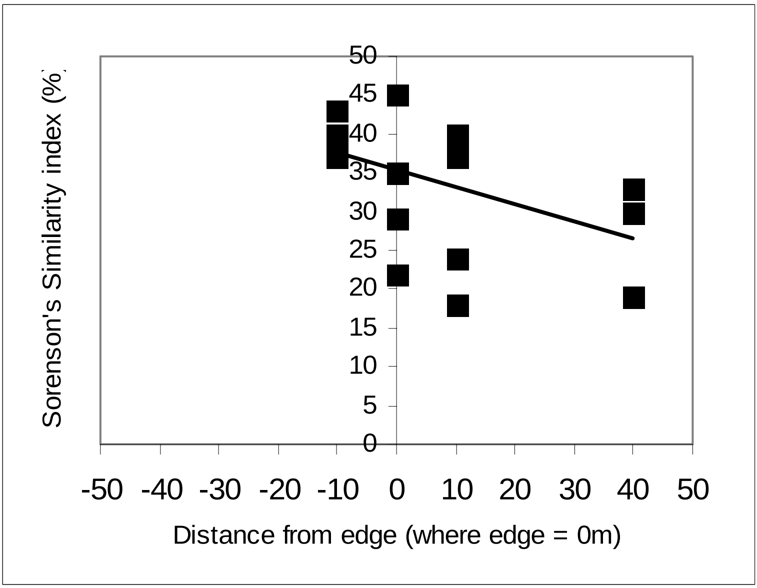

Fig. 5: Decline in faunal overlap: looking at the similarity of species found at 40 m into the forest to that found at 10 m into the forest (-10), edge (0), 10 m and 40 m into the tea (+10, +40).

Species diversity. A total of 161 arthropod taxa were assigned to morpho-types (Table 1). The mean number of species occurring at different distances from the edge differed significantly from each other ($F_{4.60}$ = 6.47, p <0.001; Fig. 3). It is evident that the greatest mean number of species sampled occurred at the edge (32 ± 2.6 species sampled per site), with changes in species numbers from edge to forest (30 ± 3.4 at –10 m & 28 ± 1.1 –40 m) being less obvious than from edge to tea (18 ± 2.3 at +10 m & 16 ± 2.3 at 40 m), where the number of species almost halves (Fig. 4).

Faunal overlap. The general trend shows species similarity declining with distance from the initial sampling site measured. Slopes were generated to describe the rate of this decline in similarity of species identified, comparing similarity in samples collected at 40 m into the forest with that found at 10 in the forest (-10), at the edge (0), 10 m into the tea (+10) and 40 m into the tea (+40m; Fig. 5). The slope of y = -0.2x + 35.4 was identified, with distance being responsible for 23 % of this decline in the similarity of species sampled (R^2 = 0.23; regression analysis, $F_{1.14}$ = 6.22, p <0.05).

Discussion

Arthropod abundance. Abundance was found to change significantly with distance, declining from forest to tea, with the number of individuals found at 40 m into tea being effectively 50 % of that found at 40 m into the forest habitat. Abundance in the forest towards the edge showed no real decline, while at edge arthropod abundance was almost three times greater than that encountered 10 m into the tea plantation.

The forest represents greater niche and microclimate heterogeneity due to higher floral diversity and complexity in forest structure. A greater availability of resources such as food, nesting sites, may enable a more favourable habitat to exist, whilst lower temperature extremes and higher moisture content recorded may facilitate and promote mobility of terrestrial invertebrates that may otherwise be highly susceptible to desiccation. Such promotion of mobility may in turn accommodate an increase in foraging effort for example, and could further enhance habitat flexibility, whereby an organism is no longer restricted to a single habitat type. As such, the threshold of abundance within such a heterogeneous ecosystem could be enhanced.

Greater similarity in abiotic conditions between the forest and edge most likely support the maintenance of high species abundance. The edge inherently shares some of the heterogeneity of the forest, and also receives shade from the canopy overhead. Physical parameters such as wind, light intensity, humidity and temperature are therefore less likely to undergo fluctuations as extreme as in the tea habitat. To contrast, the homogeneity and structural simplicity of the tea plantation may be responsible for a reduced diversity of hospitable niches, restricting the threshold of individuals supported within this habitat.

Arthropod diversity. The edge exhibited the greatest arthropod diversity in terms of number of morpho-types (~species) sampled. Diversity within the forest did not significantly differ to that at the edge, but arthropod diversity of the forest and edge differed significantly to that found in the tea plantation. Our data indicates that the heterogeneous forest matrix supported a greater arthropod diversity. In addition, the edge may represent an area where both species communities from either habitat can co-exist, by offering alternative, potential niches. For example, some arthropod species found within the forest habitat that may not necessarily be well adapted to the high moisture of the forest, and thus may exist more successfully at the drier edge. Similarly, species that inhabit the tea environment may exist more optimally at the edge, where greater moisture or shading occurs.

Alternatively this edge may represent a boundary that species adapted to either habitat type cannot cross. Their dispersal ability and ecology will therefore ultimately define how fine or coarse the edge will appear specifically to them, and may explain why the number of species found in the forest and at the edge drops to over half that sampled when crossing over to the tea habitat. It may be that only the more generalist species, or those species that can regulate or tolerate factors such as water loss, reduced niche heterogeneity and food resource, can effectively cross the boundary into the tea habitat. Alternatively, species composition within the tea habitat may comprise of a very different species community that may be specialised or adapted to the environment offered by the monoculture plantation.

Arthropod similarity. The general trend of declining similarity in species composition as one moves away from a point of origin, is immediately apparent from our data. Higher abundance and diversity within the forest habitat, along with more favourable abiotic conditions promoting and facilitating mobility to the edge, can explain why the similarity in 'forest-habitat species' to those species sampled at the edge was found to be higher than when looking at the similarity of 'tea-habitat species' to those found at the edge.

The decline in similarity of 'forest-habitat species' sampled when moving from the forest to tea is significantly greater in magnitude than the decline in similarity of 'tea-habitat species' to those sampled within the forest. From this we can assume that the sharp change in diversity described earlier between the edge and tea habitat may be more likely due to the presence of a completely different species composition rather than a reduced one. However the relationship between similarity and distance is not strong, with only 23 % of this rate of decline accounted for by distance, and hence the latter explanation cannot be dismissed (it is most likely that both circumstances may be occurring).

Conclusions. It is clear that the boundary between primary, tropical, sub-montane forest and tea monoculture offers a strong contrast in habitat types and related abundance, diversity and similarity in species composition. The apparency of this edge is evident through both physical and biological parameters studied here, whilst the degree to which this edge acts as a barrier will ultimately and crucially depend on the ecology of the species in question. Consideration of terrestrial invertebrates in this study enabled us to consider shorter distances over which to measure and identify edge effects. More crucially it is apparent from this preliminary study that even over such short distances edge effects on biota diversity and abundance do exist. In an already heavily fragmented habitat where patches are continually being created either naturally or artificially, the widening of the fragmented extent is inevitable in the future. It is therefore important to consider to what extent such fragmentation will have on the high endemicity of flora and fauna of the East Usambaras and other similar ecologically important areas.

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