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# 19 Diversity of geometrid moths in two Neotropical rain forests

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## ABSTRACT

The diversity of geometrid moths (Lepidoptera: Geometridae) was investigated in two tropical montane cloud forests in southern Ecuador and in central Costa Rica. The study covered an elevational range from c. 1000 to 2700 m.a.s.l. in both locations. Data were analyzed for eight sites, representing four elevations in each of the two study areas. A total of 770 species (4569 specimens) were sampled in Ecuador vs. 503 in Costa Rica (7303 specimens). Sampling was incomplete and it is expected that more species will be found in both areas. Moth diversity was extremely high in Ecuador and almost invariably higher than at comparable elevations in Costa Rica. Values of Fisher's  $\alpha$  index ranged between 70 and 131 in Ecuador, and between 31 and 83 in Costa Rica. An analysis of rarefied species numbers led to very similar results. At a level of 390 rarefied specimens, the range was 131–179 species at the Ecuadorian sites, vs. 77–140 at the Costa Rican sites. Only 64 (5.3%) out of the total of 1209 species were common to both areas. The results of this study underline the fact that the tropical Andean mountains are one of the “hot spots” of local diversity of geometrid moths, and that the threatened Andean cloud forests should be given the highest priority in conservation policy. Similarly, countries like Costa Rica, which are already actively engaged in nature conservation, may find additional motivation in the present results to continue their efforts.

## INTRODUCTION

Arthropods are the dominant group of animals in tropical rain forests in terms of species numbers. Their impact on these complex ecosystems must be enormous since they are involved

in almost all ecological processes except primary production. However, knowledge of the biology and taxonomy of most arthropod taxa in tropical regions is very poor, and a large percentage of species remain to be taxonomically described. Moths play an important role both in rain forest food webs and as pollinators. However, even a basic knowledge of the diversity of most groups is lacking for many regions of the world. With c. 21 000 described species, the family Geometridae is one of the three most species-rich moth families in the world (Scoble, 1999), and more than 6000 species have been described from the Neotropics alone. Quantitative studies of the diversity of geometrid moths in South America were carried out in the southern Ecuadorian Andes by Brehm (2002), by Brehm *et al.* (2003a, b, 2005) and by Hilt *et al.* (2006, 2007). With 1266 species recorded, this was the highest number ever found regionally (Brehm *et al.*, 2005). Brehm *et al.* (2003b) further demonstrated that local diversity in southern Ecuador was extremely high, with up to 292 species recorded per site and values of Fisher's  $\alpha$  index reaching up to 131. Diversity remained high along a broad elevational gradient ranging from 1040 to 2677 m.a.s.l. (Brehm *et al.*, 2003b).

A comparable study on the diversity of geometrid moths along an extended elevational transect in montane forests in central Costa Rica was initiated in 2003. In this chapter, an answer is sought to the following questions:

- Is the local diversity of geometrid moths in the Andes higher compared to Central America, as is the case for better-known groups of organisms such as birds (e.g. Blake and Loiselle, 2000; Ridgely and Greenfield, 2001) and plants (Jørgensen and León-Yáñez, 1999; Hammel *et al.*, 2004)? Species checklists (e.g. Pitkin *et al.* (1996) for the geometrid sub-family Ennominae) suggest that moth diversity in Costa Rica could be considerably lower than in Ecuador. It was therefore expected to find lower local moth diversity in Costa Rica.

- Does geometrid diversity remain as great at high elevations in Costa Rica as in Ecuador?
- How many species occur in both regions? Own observations in museum collections, distributional data on Neotropical geometrid genera (Pitkin, 2002), and the species checklist by Pitkin *et al.* (1996) led to the hypothesis that the overlap between regional faunas is relatively low. However, the extent of this broad-scale beta diversity is unknown so far.

## MATERIAL AND METHODS

### Study sites

Sampling was carried out along extensive elevational gradients in two study areas in Ecuador and Costa Rica (e.g. Brehm *et al.*, 2005, 2007; Hilt *et al.*, 2006, 2007). This chapter concentrates on montane forests and compares a selection of four paired sites from each area ( $4 \times 2 \times 2 =$  a total of 16 sites). Elevation of the sites ranged from lower montane rain forest (at *c.* 1000 m.a.s.l.) to upper montane cloud forest (at *c.* 2750 m.a.s.l.), both in Ecuador and Costa Rica (Figure 19.1). The vegetation in both areas consists mostly of primary forest, but some selective logging had been carried out at lower elevations in Ecuador and at higher elevations in Costa Rica.

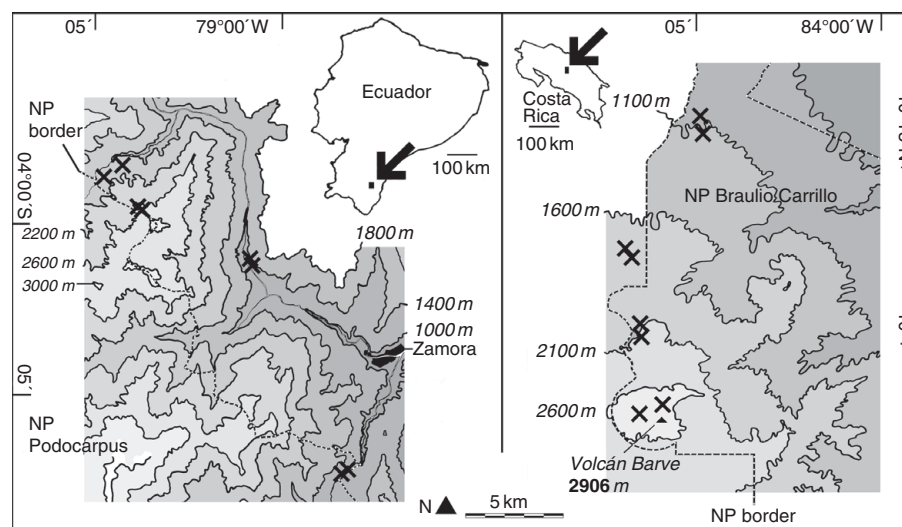
The study area in southern Ecuador is situated in the Eastern Cordillera of the Andes and forms part of the province of Zamora–Chinchipe, at the northern margin of the Podocarpus National Park. The study sites were located at elevations between 1040 m and 2677 m.a.s.l. between  $3^{\circ} 58' S$  and  $04^{\circ} 07' S$ , and between  $78^{\circ} 58' W$  and  $79^{\circ} 05' W$  (Brehm and Fiedler, 2003).

Rainfall in the area ranges between *c.* 2200 mm year<sup>-1</sup> at lower elevations and 4700 mm year<sup>-1</sup> at higher elevations (Bendix *et al.*, 2008). Results for alpha and beta diversity of 22 forest sites investigated in the same area were provided by Brehm and Fiedler (2003), and by Brehm *et al.* (2003a, b). Four paired sites (at elevations of 1040, 1380, 2005, and 2670 m.a.s.l.) were selected for this study (Figure 19.1).

The study area in Costa Rica is situated in the central Cordillera (Heredia province). The eight study sites were located within the Braulio Carrillo National Park (Barva transect) or close to its western boundaries (1070–2730 m.a.s.l.) between  $10^{\circ} 08' N$  and  $10^{\circ} 16' N$ , and between  $84^{\circ} 05' W$  and  $84^{\circ} 07' W$  at elevations of *c.* 1090, 1700, 2115, and 2730 m.a.s.l. (Figure 19.1). Rainfall in the lower montane rain forest zone on Volcán Barva below 2000 m.a.s.l. exceeds 4000 mm year<sup>-1</sup> and decreases to *c.* 3300 mm year<sup>-1</sup> at higher elevations. Lower montane (cloud) forest occurs at 2100 and upper montane cloud forest at 2600 m.a.s.l. (Heaney and Proctor, 1990). The role of environment and the “mid-domain effect” on moth species richness along the complete Barva transect was analyzed in detail by Brehm *et al.* (2007).

### Sampling and identification of moths

Moths were sampled manually using portable light-traps consisting of two 15 W UV tubes (Sylvania blacklight-blue, F15W/T8/BLB and Philips TLD 15W 05) and a white gauze cylinder (height 1.60 m, diameter 0.70 m). Sampling methods were as described and discussed by Brehm and Axmacher (2006). Light-traps were run during the peak of moth activity at dusk between 18.30 and 21.30 h. The Ecuadorian sites were sampled two to



**Figure 19.1.** Study areas in Ecuador (left) and Costa Rica (right). In each area, the eight study sites are marked with crosses (×). Site positions were measured using the Global Positioning System. Other geographic information was taken from 1:50 000 topographic maps. Note that contour lines are spaced by 400 m in Ecuador and by 500 m in Costa Rica. NP, National Park.

four times in April, May, and December 1999 (Brehm, 2002; Brehm and Fiedler, 2003); those in Costa Rica were sampled twice, in April and May 2003. Further samples (two or three at each site) taken in 2004 were similar both in species composition and diversity. Combined samples from both years showed only slight deviations from the results presented here (Brehm *et al.*, 2007). In both areas, there is no strong seasonality, but the relatively short sampling periods may have had some influence on the results. Although the number of samples was low, a meaningful analysis appeared to be possible because each sample was large and contained at least 390 specimens.

Specimens were identified by the author as far as possible in the Natural History Museum in London (BMNH), the National Museum of Natural History in Washington DC (USNM), the American Museum of Natural History in New York (AMNH), and the Zoologische Staatssammlung München (ZSM). For both study areas, a high proportion (37–47%) of the species appear to be undescribed so far (Brehm *et al.*, 2005, 2007).

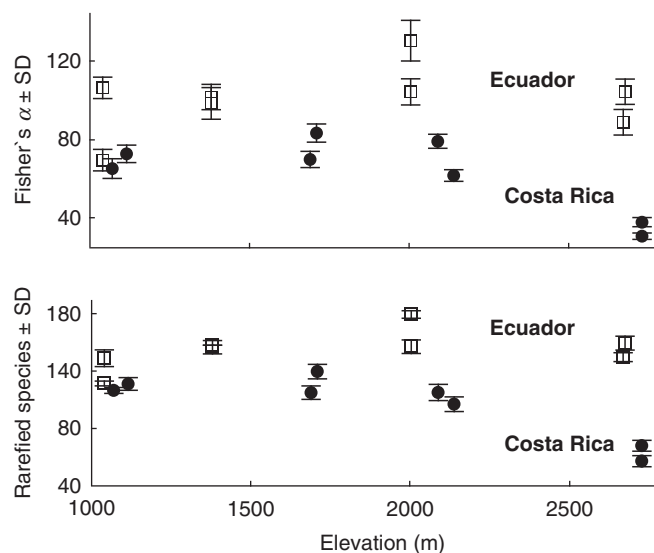
### Statistical analysis

Fisher's  $\alpha$  index was chosen as a measure for local diversity since it has been proven to be relatively insensitive to under-sampling (Magurran, 2004). The rarefaction method was used as an additional measure of local diversity because it is particularly useful in samples of different size (Hurlbert, 1971). Rarefied species numbers at the level of 390 specimens were calculated using a program developed by Kenney and Krebs (2000); 390 is the specimen number in the smallest sample.

Data on the moth ensembles of the sites were ordinated by non-metric multidimensional scaling (NMDS) using Statistica 5.5 software (StatSoft, Tulsa, OK, USA). The NESS index (Grassle and Smith, 1976) with the sample size parameter  $m$  set to its maximum was chosen because it was recommended as an appropriate abundance-based index for incompletely sampled, species-rich moth ensembles (Brehm and Fiedler, 2004). It was calculated using a program provided by Messner (1996). Ordinations based on the NESS index with  $m$  set to 1 as well as an ordination based on the Sørensen index led to very similar results and these are therefore not presented.

## RESULTS

Figure 19.2 displays values of Fisher's  $\alpha$  index and rarefied species numbers for the respective paired sites. Despite their different mathematic approaches, both methods gave very similar results. With one exception (1040 m.a.s.l.), all ensembles from Ecuador were more diverse than those from Costa Rica. Fisher's  $\alpha$  index ranged between 70 and 131 for the Ecuadorian sites, and between 31 and 83 for the Costa Rican sites. Similarly,



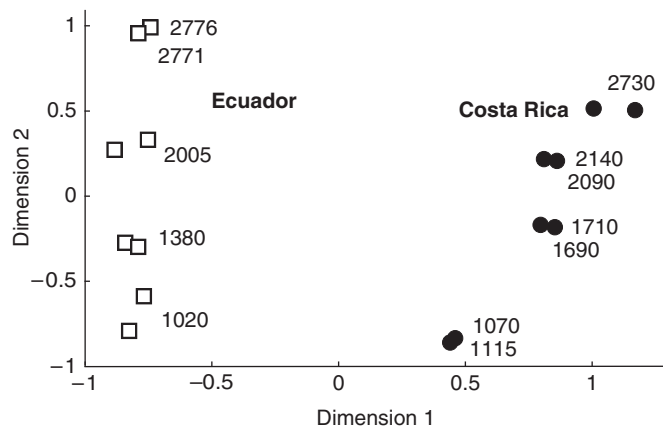
**Figure 19.2.** Local diversity of geometrid moths in two tropical montane forest areas in Ecuador and Costa Rica based on Fisher's  $\alpha$  index and on rarefied species numbers (at the level of 390 specimens).

using a rarefaction level of 390 specimens, the range derived for the Ecuadorian sites was 131–179 species, vs. 77–140 species for the Costa Rican sites. Whilst geometrid moths in Ecuador remained highly diverse along the complete elevational gradient, diversity decreased markedly at the uppermost pair of sites in the upper montane cloud forest zone at 2730 m.a.s.l. in Costa Rica (Figure 19.2).

In Costa Rica 503 species of geometrid moths were found in the investigated gradient, whereas the total from Ecuador was 770, i.e. *c.* 50% more species, despite the fact that the number of individuals analyzed from Ecuador was considerably smaller than that from Costa Rica (4569 vs. 7303). In both cases, species numbers are underestimations (see Brehm *et al.*, 2005, 2007 for extended species lists).

The results of the ordination analysis are summarized in Figure 19.3. The first dimension of the NMDS clearly divides the two geographic groups of samples, whereas the sites are ordered according to their elevation along the second dimension. Extracted scores of the second dimension of the ordination were strongly correlated with site elevation (Ecuador:  $r_s = 0.96$ , Costa Rica:  $r_s = 0.97$ ,  $p < 0.001$  in both cases). This shows that the most important factor in the ordination is geographic position, followed by site elevation. Elevations did not correspond perfectly between the Costa Rican and Ecuadorian samples, i.e. the Costa Rican samples were ordered slightly “lower.”

Species overlap proved very limited: from the total of 1208 species analyzed in this study, only 64 (5.3%) were shared between the areas. Although this number might be an underestimate due to the incomplete sampling, it seems likely that the order of magnitude of overlap will not be more than 10%.



**Figure 19.3.** Non-metric two-dimensional scaling of eight moth samples from Ecuador and eight samples from Costa Rica based on the NESS dissimilarity index ( $m_{\max} = 195$ ). Information on elevations above mean sea level (in m) provided. Stress is low with an NESS value of 0.05, indicating low risk of artifactual patterns (Brehm and Fiedler, 2004).

## DISCUSSION AND CONCLUSION

Diversity of geometrid moths is clearly higher in Ecuadorian than in Costa Rican montane forests. However, diversity in Costa Rica is still very high (Figure 19.2), and at all but the highest sites exceeds values for temperate or African sites (cf. Axmacher *et al.*, 2004; overview in Brehm *et al.*, 2005). However, moth diversity in montane Costa Rica is lower than at some lowland sites in South-East Asia (e.g. Barlow and Woiwod, 1989). Whilst there were no significant differences in species richness amongst lower montane (cloud) forests between elevations of 1100 and 2100 m.a.s.l. in Costa Rica (Figure 19.2), the highest site pair in the summit area of Volcán Barva showed an order of magnitude for Fisher's  $\alpha$  index (31–38) that has also been recorded for some temperate forests (e.g. Thomas, 2002). It is nevertheless remarkable how rich the ensembles were even at this high elevation with its cold, wet, and windy climate (cf. Heaney and Proctor, 1990).

It might be argued that two samples per site in Costa Rica are not sufficient for a reliable analysis. However, at least 427 specimens were collected at each Costa Rican site, and combined results from four/six samples per elevation yielded similar, sometimes slightly higher diversity values (Brehm *et al.*, 2007) that do not affect any of the conclusions drawn here. The results thus indicate that the geometrid moth fauna in Central America is very diverse, but that the true diversity “hot spot” is clearly located in the Andes. Indeed, the Andean mountains are known as a “hyper hot spot” of diversity for many groups of organisms (e.g. Brummitt and Lughada, 2003; Brehm *et al.*, 2008). The present study supports this view for a very species-rich moth taxon. Various hypotheses potentially explain the high richness of the Andes compared with other regions (evolution and

biogeography, climate history, biotic and abiotic factors, stochastic effects; see Brehm *et al.* (2008) for discussion).

Unfortunately, Andean and sub-Andean cloud forests have less than 4.5% and 6.4% of their original pre-Columbian extent currently protected (Armenteras *et al.*, 2003) and rates of montane forest conversion in the region are high (Bubb *et al.*, 2004; Mosandl *et al.*, 2008; Mulligan, this volume). The impact of deforestation on arthropods is largely unknown, but it must be assumed that specialized moth species will become extinct if their host-plants and habitats are destroyed (Brehm and Fiedler, 2005). Climate change might further accelerate extinction with lowland biotic attrition and range shift gaps, particularly for small-ranged species (Colwell *et al.*, 2008). The present study confirms that the Andean rain forests merit a high conservation priority because of their exceptional biodiversity and the rapid loss of the last remaining fragments. However, Central American forests should not be neglected since diversity there is still very high and species overlap with the Andes surprisingly small (cf. Figure 19.3). Furthermore, there is evidence that the proportion of endemic species increases with elevation (Brehm, 2002). Thus, the maintenance of an extended National Park system in Costa Rica's mountainous regions is not only important for watershed services (cf. Calvo *et al.*, this volume), but also for the protection of a unique component of the world's biodiversity. Further studies in both Central America and the Andes will improve our understanding of diversity patterns and help to better define priority areas for conservation on a regional scale (Myers *et al.*, 2000; cf. Leo, 1995; Catchpole and Kirkpatrick, this volume; Cavelier *et al.*, this volume; Mulligan, this volume).

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