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Research Article

Seasonal diversity of butterflies and its relationship with woody-plant resources availability in an Ecuadorian tropical dry forest

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Abstract

Understanding the seasonal community structures of highly diverse animal taxa and how they interact with plants is necessary for efficient conservation efforts such as rapid biodiversity inventory protocols and monitoring programs. This knowledge is particularly important for seasonal tropical dry forests, which are among the most threatened ecosystems on the planet. We sampled a seasonal tropical dry forest over the course of a year to determine the period of greatest butterfly richness. Additionally, we evaluated availability of potential woody plant trophic resources (flower buds, blossoms, unripe fruits, ripe fruits, and foliage) in relation to butterfly richness and community composition. Twenty of the 22 species collected showed flight activity between January-April (rainy season), coinciding with maximum plant resources availability. Lepidoptera species richness correlated positively with amount of ripe fruits and foliage. Community composition changes among sample dates involved losses and gains, and not turnovers, of species. These shifts correlate with seasonal oscillations in the variety of ripe fruits and the amount of foliage. Our results indicate that rapid inventory protocols may be applied in the period of February-March; species richness monitoring can be restricted to the rainy season (saving labor and economic costs); and ripe fruits and foliage may be suitable candidates for temporal plant-butterfly interaction surveillance.

Key words: Community structure, bioindicators, plant-insect interactions, seasonal dynamics.

Resumen

La comprensión de la dinámica estacional de la estructura de la comunidad de taxa animales de alta diversidad y su interacción con las plantas es necesaria para aplicar eficientemente herramientas de conservación tales como inventarios rápidos de biodiversidad y programas de seguimiento. Este conocimiento, es especialmente importante en los bosques tropicales estacionalmente secos debido a que se encuentran entre los más amenazados del planeta. Con el fin de determinar el periodo de mayor riqueza específica de mariposas, se muestreó durante un año en un bosque estacionalmente seco del sur del Ecuador. Adicionalmente evaluamos la disponibilidad de potenciales recursos tróficos de plantas leñosas (flores cerradas y abiertas, frutos maduros e inmaduros y follaje) para explorar las relaciones entre la riqueza y la composición de la comunidad de mariposas con la disponibilidad de los recursos vegetales. Veinte de las 22 especies capturadas mostraron actividad voladora en enero-abril (estación lluviosa), coincidiendo con la mayor disponibilidad de recursos vegetales. La riqueza de lepidópteros se correlacionó positivamente con la cantidad de frutos maduros y de follaje. Los cambios en composición de la comunidad entre fechas de muestreo consistieron en pérdidas y ganancias, y no reemplazos, de especies. Los resultados indican que los inventarios rápidos de biodiversidad podrían aplicarse en el periodo febrero-marzo y que el seguimiento de la riqueza específica podría restringirse a la estación lluviosa (ahorrando costes económicos y temporales). Además, los frutos maduros y el follaje se muestran como candidatos apropiados para el seguimiento temporal de las interacciones planta-mariposas.

Palabras clave: Estructura de la comunidad, bioindicadores, interacciones planta-insecto, dinámicas estacionales.

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Introduction

Understanding seasonal dynamics of community structure and community relationships with availability of resources is necessary for more efficient and cost-effective monitoring of biodiversity indicators and threatened taxa [1-8]. Such monitoring is especially urgent in seasonally dry tropical forests, because they are among the most endangered ecosystems in the world, showing annual deforestation rates between 2- 4.6% in Neotropical areas [9]. This situation is exacerbated in Ecuador, where the deforestation rate is probably the highest in South America [10]. It has been estimated that the extent of tropical dry forest in Ecuador has been reduced to 19.4% (3,716 km^2) of its original area, with the lowland dry forests in southwest Ecuador showing the highest percentage (81.6%) of deforestation [11]. The main cause of their destruction is the conversion to agricultural lands, followed by ranching and timber exploitation [10-12]. These activities threaten the biodiversity of tropical dry forests of the Equatorial Pacific region (located in southwestern Ecuador and northwestern Peru), considered among the most important endemism zones in the world [13-16]. Only 5% of the approximately 55,000 km^2 of the remaining tropical forests of the Equatorial Pacific region are being conserved by some form of protected area [15], and many are degraded due to anthropic pressures [12]. Despite their precarious status and their importance as suppliers of ecosystem services and goods for human wellbeing [17,18], the biodiversity and ecological dynamics of neotropical dry forests are still poorly understood [19]. Inside the Equatoral Pacific region, the Arenillas Ecological Reserve forest, declared as a protected area 60 years ago, is the largest well-preserved, lowland dry forest in southwest Ecuador [20, 21].

Research so far has revealed that with a few exceptions [22], taxa richness and availability of trophic resources in tropical dry ecosystems usually peak during the wet season [23-30]. However, only a fraction of these works completed an entire year of sampling [26-29], or determined which trophic resources are more related to seasonal changes in diversity [26]. Although the literature suggests that the richness peak observed in the rainy season is mainly due to gains rather than replacement of species over time, this hypothesis has not been analyzed directly and needs testing to determine whether monitoring and inventorying should be split into more than one sample period.

Diurnal butterflies are preferred indicators of habitat disturbance because of their sensitivity to environmental changes, diversity, advanced taxonomy, and lower economic and temporal costs of collection [4, 31-33]. They also have been used as models to monitor temporal changes in plant-insect interactions, because climate change induces phenological mismatches between butterflies and their exploited plant species that can produce changes in trophic webs [34-36]. This is especially important because global climate change is expected to rapidly affect tropical regions [37]. Further, although tropical species consume a wide range of plant resources [4, 38], we do not yet know which resources are more related to diversity oscillations of butterflies in tropical dry forests.

To identify the most suitable periods of the year for inventory and monitoring programs and the potential plant resources (flowers, fruits, foliage) most related to seasonal changes of butterfly flying activity, we analyzed data from an entire year of sampling. We first checked whether the observed species richness and communities differed among sampling dates. We also tested whether the activity of species and availability of potential woody plant resources were concentrated seasonally. Finally, we used correlation procedures to analyze whether species richness and abundance synchronized with amount and variety of potential woody plant resources. We expected that species richness and community composition would differ among sampling dates and correlate with woody plant resources.

Methods

Study Area

The study was conducted at the Arenillas Ecological Reserve (REA), located in southwestern Ecuador, in the El Oro province (Fig. 1). The reserve covers 16,958 hectares, with an altitudinal range of 0-300 m.a.s.l. The climate is characterized by four months of rainy season (January-April) and eight months of dry season (INAHMI, National Institute of Meteorology and Hydrology of Ecuador. 39 years of data sets). The average annual rainfall is 668 mm, of which 516 mm occur in the rainy season and 152 mm in the dry season. The average temperature (24.2°C) has a maximum oscillation of 3.4 °C between the warmest (April) and coldest (August) months, with lower temperatures during the dry season.

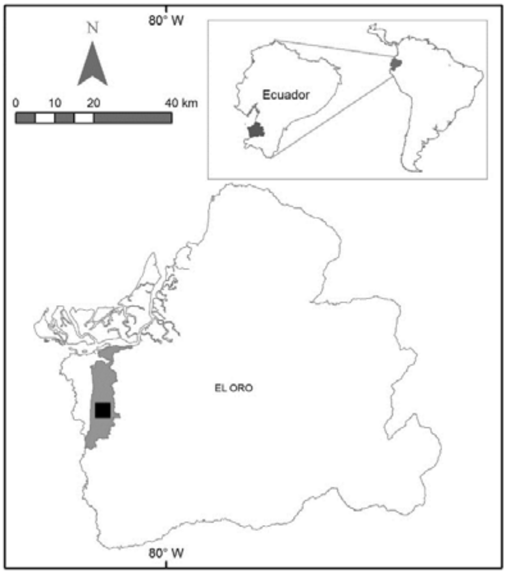

Fig. 1. Location of the study area (black square). The grey shade indicates the area of the Ecological Reserve of Arenillas.

Research was carried out in a tropical lowland dry forest located in a flat land (30 - 50 m.a.s.l.), that forms part of a forest-scrub transition, with predominance of deciduous plant species, which lose their leaves during the dry season [39, 40]. The sparse canopy layer is mainly made up of *Tabebuia*, *Geoffroea*, *Ceiba*, and *Colicodendron* tree genera. The understory and shrub layers are composed mostly of thorny and stocky vegetation such as columnar cactus and woody legumes. Woody plants show an average height of 6.3 m, and 90% do not exceed 11 m (Espinosa, unpublished data).

Butterfly Collection

Butterflies were successively sampled during nine months between December 2011 and October 2012, including all the rainy season and five months of the dry season. Sampling was not carried out in May, June, and November because the study area was not accessible during these months. Adult butterflies were collected using Van Sommeren-Rydon traps [41, 42] baited with fermented fruits (banana, pineapple, papaya, and sugar cane juice) and with a butterfly net. These methods were selected as complementary after carrying out a pilot study using other baits such as fish and honey. The species composition collected by nets and traps differed, and we observed that some species attracted by fruits also visited the other baits. A total of 12 traps were distributed in two, 250 m parallel rows 100 m apart. The central UTM coordinates of this 250 x 100 m plot were 594806 m E, 9605275 m S, and 43 m.a.s.l. (datum WGS 84). This sampling site was selected as representative of forest fauna . It was located in a central position of the forest and far from the nearest watercourse (Bejucal stream, 2.8 km away from the sampling site). In each row, traps were placed 50 m apart and 1.5 m above ground level [42]. Traps were active three days per month, from 7 to 10 a.m. and 3 to 6 p.m., with a total annual sampling effort of 1,944 h. Catches with butterfly nets were carried out on the same dates, in the same schedule, by walking the two 250 m sampling rows and collecting all the butterflies visible on both sides of each transect. Individuals collected by this method were pooled with those found in the nearest trap. Thereby, a total of 12 sampling units were considered. All the collected material was examined in the laboratory and classified to species level. Identifications were performed using taxonomic revisions of Ecuadorian butterflies [43-45]. The specimens were deposited in the Museum of Invertebrates of the Natural Sciences Department of the Universidad Técnica Particular de Loja.

Quantification of Tree Resources

Three plots of 20x20 m were placed in the center and opposite corners of the trap sample grid. In each plot, all trees with dbh>10 cm were tagged, measured and identified. We monitored the amount of five potential tree resources (flower-buds, blossoms, unripe fruits, ripe fruits, and foliage) of 49 trees belonging to 12 species. For each tree resource per tree, the same observer estimated visually the percentage cover of its potential canopy (tree crown) fullness [46] using five categories; 0%, 25%, 50%, 75%, and 100%. Resource amount was calculated as the average of the percentages of all individuals. Data were registered on the same sampling dates as butterfly collection.

These potential food resources provided by trees were selected for two reasons: 1) in terms of biomass, trees were the dominant vegetation, and 2) these vegetation resources were the easiest and quickest to quantify as potential indicators of butterfly-plant relationship monitoring.

Data Treatment

The number of individuals collected and tree resource abundance were registered and arranged in two matrices: one of species (rows) and months (columns), and the other of tree resources (rows) and months (columns). In a first step, we estimated the inventory completeness performing an individual-based rarefaction curve for the whole butterfly sample (all the sampling dates pooled) and two non-parametric estimators of species richness, Chao 1 and ACE [47]. The individual-based rarefaction approach was necessary in order to avoid the bias due to spatial autocorrelation in taxon occurrence among sampling units [47,48]. The analysis of the seasonal dynamics of the diversity and structure of the community (and of most abundant species) and their relationships with availability of tree resources is described below).

We used rarefaction of species richness estimation for individual-based data [49] to determine the sample dates with the highest and lowest species richness. Next, we applied two analyses of rarefaction for all sample dates. The first was to interpolate the species richness accumulated for the number of individuals observed in the less abundant sample. The second was to extrapolate the number of individuals observed in the most abundant sample. Samples with no-overlapping confidence intervals (95%) were considered statistically significant. All the rarefaction analyses were computed using EstimateS Version 9 [39].

Temporal analyses of Lepidoptera species and types of tree resources were performed using a null model which employs a randomization algorithm (Rosario) that preserves much of the temporal autocorrelation typical of ecological data sets taken over time [50]. This analysis was carried out with the help of the TimeOverlap 1.0 program), which calculates the Pianka and Czekanowski overlap indices. (http://hydrodictyon.eeb.uconn.edu/people/willig/Research/activity%20pattern.html.

We displayed non-metric, multidimensional scaling ordination plots (NMDS) in a Q-mode analysis to check for patterns of community similarities among months [51,52]. We generated four ordination plots from four different distance matrices. Matrices were built using two indices of dissimilarity of presence/absence and another two from abundance data of species. We selected the Simpson (turnover) and nestedness presence/absence indices, because the first is an indicator of species replacement of some species by others and the second a detector of species loss (or gain) between samples [53]. Likewise, we choose the herein called balance and gradient indices to analyze whether variations in abundance between pairs of samples (months) were due to substitutions of individuals of some species in one sample by the same number of individuals of different species in another sample (balance), or just loss of some individuals from one sample to the other (gradient) [54]. Indices and matrices of distances were obtained in R 3.0.2. [55] using the betapart package [56]. Then distance matrices were exported to STATISTICA 8.0 software [57] to perform the NMDS ordinations.

For each tree resource we took the percentage of its potential canopy fullness as an indicator of the amount of availability of tree resources. For each tree resource, we also registered the species richness of trees bearing the resource as an indicator of the variety of available tree resources. To test whether the availability of the five tree resources was related to temporal oscillations of species richness and activity of the most abundant butterfly species, we computed independent Spearman´s correlation coefficients, because data did not meet parametric and lack of collinearity assumptions. We also obtained three new variables: flowers (combining buds and blossoms), fruits (ripe and unripe), and all tree resources. To do this, we first standardized the data of each of the five variables multiplying each value (tree resource per sampling date) by 100 and dividing the product by the sum of the values of all sampling dates. Second, we pooled the resulting values in three groups to get the three new variables. Correlation analyses were carried out by means of STATISTICA 8.0 software [57].

Finally, we tested whether the amount and diversity of tree resources (taken as predictor variables) were correlated with changes in community dissimilarities among months, applying multivariate multiple regression on each one of the four indices of dissimilarity using the computer program DISTLM forward [58, 59]. As some predictor variables were correlated, for each distance index, individual regression analyses were performed for eight independent variables: percent of coverage of flower-buds, blossoms, unripe fruits, ripe fruits, foliage, flowers (effect of buds and blossoms together), fruits (ripe and unripe fruits), and all tree resources together.

For all statistical tests P-values were established at a 0.05 threshold. However, for each data set of multiple tests (correlations and regressions per each response variable and group [amount and variety of resources] of predictor variables) we controlled the false discovery rate for independent or positively correlated explanatory variables [60, 61], conditions met by our data. False discovery rate corrections were computed using a custom Matlab implementation of the method described by Benjamini and Hochberg [60].

Results

The sampling effort yielded a total of 865 individuals and 22 species included in five families (Appendix 1.). The rarefaction curve did not asymptotize, but those of the two species richness estimators tended to stabilize in the last tens of individuals (Fig. 2). Both richness estimators yielded a value of 25.33 species, which estimates that sampling registered 86.85% of the species present. The three most abundant species accounted for the 93.29% of the total catch: *Hamadryas februa* (75.02%), *Fountainea eurypyle* (14.45%), and *Eurema dayra* (3.82%). None of the other 19 species had a numerical representation higher than 0.69%.

Seasonal dynamics of species richness

The number of species collected as a function of abundance standardized to 16 individuals (corresponding to October, the month with the lowest abundance recorded) and extrapolated to 241 individuals (corresponding to December, the month with the highest abundance observed), showed February and March as the months that concentrated the highest diversity (Fig. 3). These two months together accounted for 77.27% of all species found. Additionally, 20 species (90.91%) were collected in the rainy season (January-April). The minimum richness took place in October with only two species recorded: *H. februa* and *F. eurypyle*. These species were the only ones active during the entire sampling period.

The narrower confidence intervals during the July-October period in all the richness estimators indicate that the inventory of species was more complete in these months than in the period from December to April (Fig. 3). Thus differences in estimated accumulated species richness as a function of observed abundance between both periods became larger in extrapolation to 241 individuals compared to standardization to 16 individuals.

The analysis of assemblage-wide temporal niche overlap showed that mean values of both overlap indices (Pianka = 0.326, Czekanowski = 0.249) were higher than expected by chance (Ps < 0.001), and therefore indicated a seasonal aggregation in the activity of species. Likewise, tree resources followed an aggregated pattern (Pianka = 0.585, P = 0.048, Czekanowski = 0.496, P = 0.028). High values of availability of all tree resources coincided in February, and were lowest in September-October, when only a few percentage of foliage cover was found (Appendix 1.). On the whole, tree resources followed unimodal dynamics, with the exception of flower buds and blossoms, which peaked in the first half of the rainy period and in July.

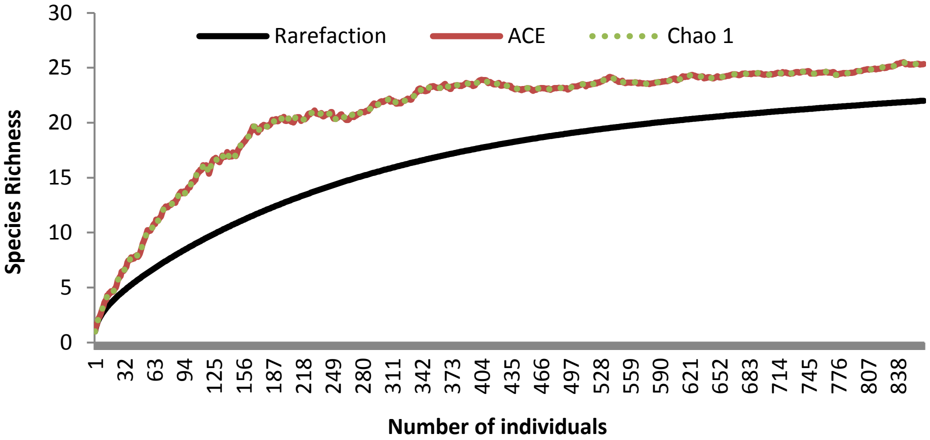

Fig. 2. Number of species observed as a function of individuals collected (rarefaction), and estimated by means of two non-parametric estimators of species richness (ACE and Chao 1).

Variations in community dissimilarities

Ordination analysis of the distances of the quantitative indices of dissimilarity (balance and gradient) among sampling dates revealed clear groups only for the gradient index (Fig. 4). This ordination separated the months according to the recorded abundance of *H. februa*. Thereby, April, March and December registered the maximum, October the minimum, and the remaining months an intermediate abundance of this species, respectively. The ordinations based on qualitative indices (turnover and nestedness) showed interpretable results for the nestedness analysis. This grouped the driest months in the negative sector of the horizontal axis, and isolated October from the rest.

Relationships of species richness, abundances and community dissimilarities with availability of tree resources

The seasonal variation of species richness was positively correlated with the amount of ripe fruits, ripe and unripe fruits combined, and amount of foliage, but not with the other potential tree resources (Appendix 2.). The overall abundance of butterflies and of the three most abundant species (*H. februa*, *E. dayra* and *F. eurypyle*) showed no correlations with tree resources (Spearman´s R correlation coefficients Ps > 0.051). Following the same trend, the pooled abundance of the 19 remaining species did not correlate positively with any tree resources (Ps > 0.0008, not significant after false discovery rates corrections).

Shifts of community composition only correlated positively with amount of foliage and diversity of ripe fruits for nestedness analyses (Appendix 3.). All the other similarity indices showed no significant relationship to availability of tree resources.

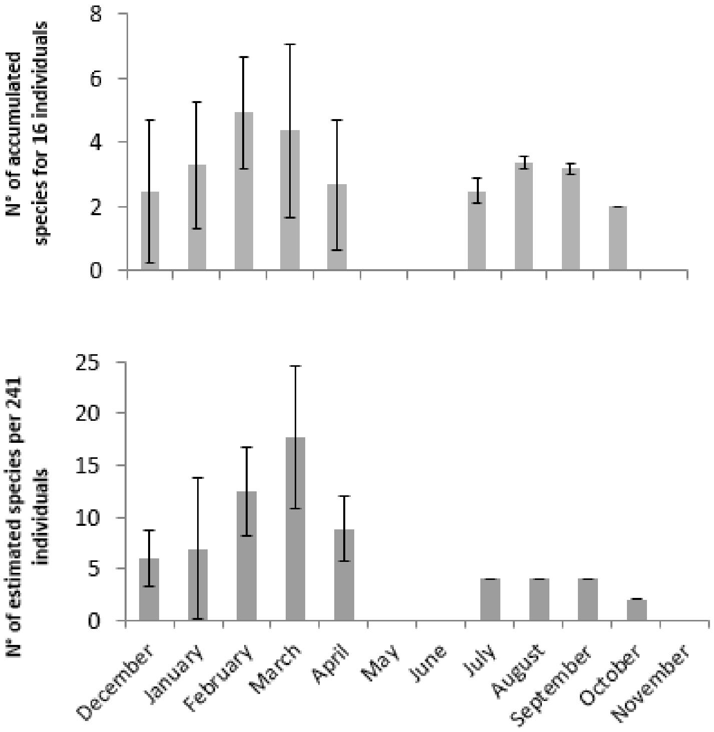

Fig. 3. Number of species observed as a function of number of individuals interpolated to the sample with the lowest abundance (top), and number of individuals extrapolated to the sample with the highest abundance (bottom). Error bars correspond to 95% confidence intervals. Sampling was not possible on May, June and November (see text for more details).

Discussion

Before discussing the results, we point out that we consider that our sampling effort provides a representative sample of the butterfly community of the study site for three reasons. First, it is has been estimated that almost 87% of the species present have been found. Second, three species account for more than 93% of individuals, implying that only very rare species remained out of the inventory. And third, according to rarefaction analysis (Fig. 2), the slope to increase from 21 to 22 species is 0.006, and since the slope decreases with the abundance, this means that around 200 more individuals (almost a quarter of the sample size) should be collected to detect a new species. Therefore, these results suggest that patterns detected actually reflect natural patterns.

Regarding seasonal dynamics of species richness, we observed that twenty of the 22 species were collected between January and April (rainy season), and only 2 species (9%) were found in the dry season. Temporal community composition changes were mostly due to gains or losses rather than replacement of species. These findings are consistent with those found in other dry ecosystems such as the Brazilian forest of Mata Seca National Park [30] and Caatinga of Catimbau National Park [28], where only 3 (8.6%) and 2 (13.3%) species, respectively, were exclusively observed in the dry season. More research is required to verify whether this pattern can be generalized to seasonally tropical dry ecosystems. Because differences in seasonality and diversity of Lepidoptera between canopy and lower strata have been demonstrated in tropical forests of South America [1, 30], our conclusions for Arenillas may be limited to the understory and shrub strata, although in the tropical dry forest of Mata Seca only five species (14.3%) were exclusively active in the canopy [30]. However, the Arenillas forest has a lower canopy stratum (Espinosa, unpublished data) than the forest of Mata Seca [62]. Therefore, differences in the number of unshared species among strata could be smaller in Arenillas.

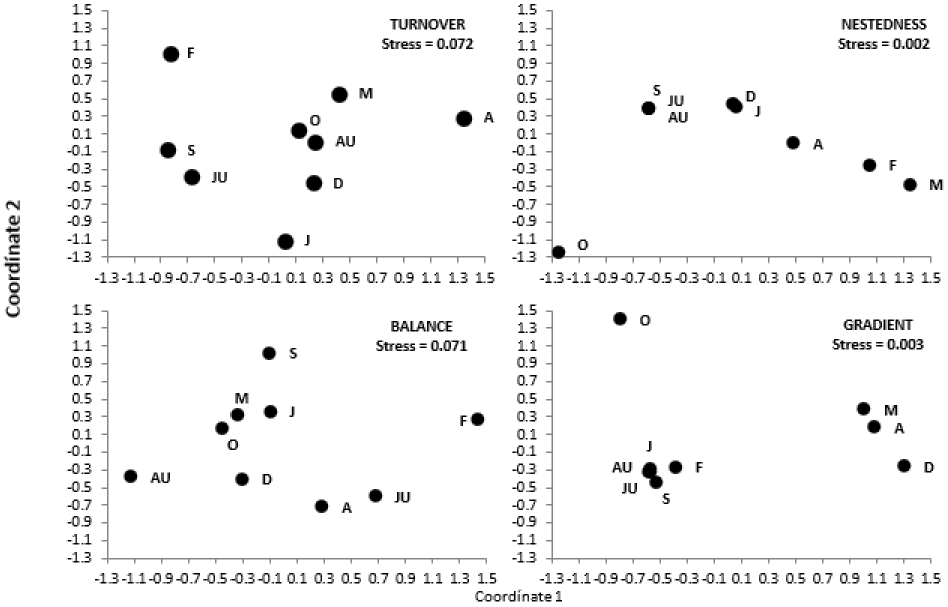

Fig. 4. NMDS ordination plots of month samples based on four dissimilarity indices: turnover (= Simpson) and nestedness (incidence-based), and balance and gradient (abundance-based). Abbreviations: A – April, AU – August, D – December, F – February, J – January, JU – July, M – March, O – October, S – September.

A likely cause for greater flying activity of most species in the rainy season is the greater availability of food [29]. Our results support this reasoning, since both the amount and variety of potential tree resources were greatest in the wet season. Data suggest that variety and amount of ripe fruits and amount of foliage are the main tree resource drivers of diversity, but not abundance variation, of butterflies. In the case of ripe fruits, the variety available could provide a greater diversity of nutrients, which has been related to greater reproductive success [63]. Regarding the foliage, the best quality of host plants is more likely to occur in the rainy season, when leaves reach their fullest development. Hence, it is not surprising that most butterfly species concentrate their activity in this season, when the majority lay their eggs on vegetation [23]. However, the maintenance of foliage on several tree species (February to August) without correlation to tree richness and Lepidoptera richness and abundance, may indicate that the palatability of leaves decreases after the last part of the rainy season. Accordingly, it has been suggested that herbivore insects, including Lepidoptera, usually avoid feeding on mature leaves [64, 65].

Unexpectedly, we did not find any evidence of a relationship between availability of flowers and activity of butterflies. This is a striking result, because diet research has shown that adults in the tropics feed mainly on pollen and nectar [24]. We also collected at least six species (*Chioides catillus*, *Agraulis vanillae*, *Heliconius charithonia*, *Junonia evarete*, *Ascia monuste*, and *Phoebis argante*) whose adults are known to visit flowers [66-70]. The presence of these species and peaks of abundance and variety of flowers did not happen at the same time (see also Appendix 1.), suggesting that other factors could be determining their seasonal dynamics. This is supported by the fact that some of these species also visit other resources like dungs and moist mud and sand [67-70]. Because we lack information about resources visited by adults of 12 species (54.5% of the species collected), it is possible that the community of diurnal Lepidoptera of Arenillas is mostly composed of species with no feeding preference for flowers. However, other factors such as vegetation and forest stratum sampled could explain our results. We did not quantify vegetation resources from small woody (dbh Ø < 10 cm) and herb plants. Therefore, we could not detect any relations between flowers and butterflies because we did not control flowering in plants other than trees, although the small height of trees of the study site should allow an easy access to the flowers of the low canopy to most species, and probably few species would fly exclusively in the canopy of dry forests [30]. Ripe fruits were more available for the whole adult butterfly community, because fruits fallen from trees and lying on the ground can be visited by butterflies active in the understory [30].

Contrary to the trend observed by pooling the abundances of the rest of the community, the abundance of the three most abundant species (*H. februa*, *E. daira* and *F. eurypyle*) did not correlate with any tree resources. These species were the only ones active all year, and how they can cope with the dry season is hard to explain. Other more permanently available potential foods such as carrion, animal excrements, and puddles of urine are used preferentially by some species, and may play a more important role as a nutrient source than has been traditionally considered [71, 72]. More research about the autoecology of these species is needed to understand their temporal dynamics.

Implications for conservation

The environmental managers of Ecuador face the significant challenge of preserving the native biodiversity within a framework of sustainable development. This is one of the main goals of the National Plan for Good Living [73,74], which recognizes biodiversity as one the most important resources of the country. Our work contributes useful information for diversity management of a widespread indicator taxon in the tropical dry forests of southwestern Ecuador.

First, according to our data, and in order to control the biodiversity fluctuations over time, the sampling period of Lepidoptera richness monitoring programs could be standardized and restricted to the rainy season, saving time and economic costs. Our results indicate that in Arenillas, it is possible to obtain a representative diurnal-active Lepidoptera richness of the whole year in a sampling period from January to April, at least for the understory and shrub layers.

Second, as most species concentrated their activity in February and March, these months are suggested as the most appropriate to carry out rapid inventory protocols of butterfly diversity . This economizes human and financial resources in determining hot spots of diversity and how the different types and degrees of anthropic pressures affect the communities of butterflies in the dry forests of the region.

Third, our data suggest that the variety and amount of ripe fruits and amount of foliage are suitable indicators for monitoring changes in butterfly-plant interactions. These plant resources are easy to sample on woody species, and positively correlate with Lepidoptera richness. To design more accurate monitoring programs, further research should focus on determining which woody plant species are exploited by different butterfly species.

Fourth, we recommend examining carefully the relative abundances of the species before choosing the response variables to be analyzed for monitoring purposes, because we found that seasonal dynamics and correlations with plant availability resources of the three most abundant species are different from the others. These species represent a minor fraction of the species richness. This means that conclusions based on the use of the pooled abundance of all species as variable response may lead to incorrect conservation strategies.

Finally, the few studies which have looked at neotropical seasonally dry forests have found similar seasonal patterns. However, more research is needed for greater generalization. Confirming a generalized seasonal pattern would allow the standardization of monitoring programs and the comparability of their results.

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Appendix 1. Number of individuals of Lepidoptera observed per each taxon and month, and percentage of cover with respect to the potential fullness of the canopy (amount estimator) and tree richness observed per phenophase per sampling date.

	Dec.	Jan.	Feb.	Mar.	Apr.	Jul.	Aug.	Sep.	Oct.
TAXA									
Arctiidae									
Undetermined	0	0	0	1	0	0	0	0	0
Hesperiidae									
Anthoptus epictetus (Fabricius, 1793)	1	0	2	1	0	0	0	0	0
Butleria sp	0	0	0	0	0	3	0	0	0
Chioides catillus (Cramer, 1779)	0	0	2	1	1	0	0	0	0
Serdis sp	0	0	0	4	0	0	0	0	0
Lycaenidae									
Cyanoprhys remus (Hewitson, 1868)	0	0	0	1	0	0	0	0	0
Nymphalidae									
Agraulis vanillae (Linnaeus, 1758)	0	0	3	2	0	0	0	0	0
Anthanassa hermas (Röber, 1913)	0	0	3	3	0	0	0	0	0
Eunica orphise (Cramer, 1775)	0	0	0	2	2	0	0	0	0
Eunica sydonia (Gordart, 1824)	0	0	0	1	1	0	0	0	0
Fountainea eurypyle (C.&R. Felder, 1862)	32	9	2	23	16	1	22	13	7
Hamadryas amphinome (Linnaeus, 1767)	1	0	0	1	2	0	0	0	0
Hamadryas februa (Hübner, 1823)	200	32	54	99	150	54	12	39	9
Heliconius charithonia (Linnaeus, 1767)	0	0	1	0	0	0	0	0	0
Hermeuptychia hermes (Fabricius, 1775)	0	0	0	0	0	0	0	1	0
Junonia evarete (Cramer, 1782)	0	0	0	0	3	0	1	0	0
Myscelia cyaniris (Doubleday, 1848)	1	1	0	0	1	0	0	0	0
Taygetis sosis (Hopffer, 1874)	0	2	0	0	0	0	0	0	0
Pieridae									
Anteos maerula (Fabricius, 1775)	0	0	3	0	0	0	0	0	0
Ascia monuste (Linnaeus, 1764)	0	0	1	0	0	0	0	0	0
Eurema daira (Godart, 1819)	6	1	1	7	0	3	7	8	0
Phoebis argante (Fabricius, 1775)	0	0	4	1	0	0	0	0	0
TREE RESOURCES AVAILABILITY									
Amount estimator (%)									
Flower buds	0.00	2.94	6.20	1.56	0.78	7.49	2.25	0.00	0.00
Blossoms	1.52	11.76	0.78	0.00	0.00	6.76	1.52	0.00	0.00
Unripe fruits	9.74	7.58	9.15	0.00	0.78	0.78	0.78	0.00	0.00
Ripe fruits	9.83	6.07	17.51	8.23	3.03	1.56	0.78	0.00	0.00
Foliage	24.03	19.58	89.20	85.62	74.68	41.27	23.30	7.54	0.74
Tree richness									
Flower buds	0	2	2	1	1	3	2	0	0
Blossoms	1	2	1	0	0	2	2	0	0
Unripe fruits	3	2	5	0	1	1	1	0	0
Ripe fruits	4	3	8	8	2	1	1	0	0
Foliage	5	2	12	12	11	12	12	5	1

Appendix 2. Correlation analysis among species richness of butterflies observed for each month and tree resources. Significant p values, after correction of false discovery rates, are marked in bold.

Tree resource	Spearman´s correlation coefficient	95% confidence interval bounds		P
		Lowest	Highest	
Amount				
Flower-buds	0.207	-0.533	0.767	0.599
Blossoms	-0.133	-0.734	0.585	0.731
Unripe fruits	0.333	-0.428	0.818	0.384
Ripe fruits	0.851	0.427	0.968	**0.007**
Foliage	0.848	0.417	0.967	**0.006**
Flowers (buds + blossoms)	0.238	-0.508	0.781	0.536
Fruits (unripe + ripe)	0.783	0.244	0.952	**0.018**
All Resources	0.559	-0.170	0.893	0.126
Tree richness				
Flower-buds	0.106	-0.603	0.721	0.802
Blossoms	-0.181	-0.756	0.551	0.650
Unripe fruits	0.368	-0.394	0.831	0.334
Ripe fruits	0.906	0.605	0.980	0.002
Foliage	0.445	-0.315	0.857	0.240
Flowers (buds + blossoms)	0.141	-0.580	0.738	0.720
Fruits (unripe + ripe)	0.901	0.589	0.979	0.002
All Resources	0.560	-0.169	0.893	0.151

Appendix 3. Multiple regression results from distance-based multivariate analysis to test the relationships between distance matrices of four dissimilarity indices and availability of tree resources. Significant p values, after correction of false discovery rates, are marked in bold.

Distance index	Tree resource	Amount		Tree richness	
		Pseudo-F	P	Pseudo-F	P
Turnover	Flower-buds	2.245	0.167	0.737	0.556
	Blossoms	1.909	0.211	1.711	0.282
	Unripe fruits	0.863	0.553	0.668	0.578
	Ripe fruits	0.810	0.514	0.649	0.588
	Foliage	0.358	0.722	0.734	0.573
	Flowers (buds + blossoms)	2.830	0.097	0.896	0.542
	Fruits (unripe + ripe)	1.466	0.313	0.696	0.617
	All resources	3.354	0.114	0.302	0.928
Nestedness	Flower-buds	0.267	0.622	0.285	0.637
	Blossoms	-0.112	0.974	-0.078	0.944
	Unripe fruits	1.152	0.317	1.887	0.213
	Ripe fruits	7.599	0.029	15.226	**0.006**
	Foliage	20.637	**0.001**	4.058	0.079
	Flowers (buds + blossoms)	0.187	0.799	0.708	0.544
	Fruits (unripe + ripe)	5.464	0.039	8.985	0.016
	All resources	4.909	0.115	3.136	0.187
Balance	Flower-buds	4.722	0.126	-0.660	0.872
	Blossoms	0.582	0.486	-1.751	0.985
	Unripe fruits	1.515	0.326	2.464	0.220
	Ripe fruits	3.709	0.146	2.562	0.215
	Foliage	2.821	0.214	0.623	0.511
	Flowers (buds + blossoms)	2.360	0.251	0.008	0.773
	Fruits (unripe + ripe)	1.810	0.308	0.490	0.490
	All resources	0.603	0.650	0.853	0.578
Gradient	Flower-buds	-0.049	0.932	0.273	0.739
	Blossoms	0.726	0.468	0.454	0.630
	Unripe fruits	0.470	0.575	0.132	0.811
	Ripe fruits	1.263	0.314	1.722	0.225
	Foliage	2.454	0.140	1.062	0.348
	Flowers (buds + blossoms)	0.181	0.898	0.173	0.916
	Fruits (unripe + ripe)	0.628	0.593	0.862	0.499
	All resources	1.036	0.520	0.569	0.750