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ORIGINAL PAPER

An overview of Neotropical arthropod conservation efforts using risk assessment lists

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Abstract
Neotropical efforts for arthropod conservation are still insufficient. Some species from the Neotropical region have been assessed by the IUCN Red List criteria (IRL), while others have been assessed using local red lists (LRLs). Unfortunately, these two lists are completely unconnected, even when they use similar criteria to evaluate extinction risks. Therefore, an overview of arthropod conservation using the IRL and LRLs to determine general and common patterns for arthropods in the Neotropical region is still missing, and this was the main goal of our study. The LRLs provided significant information about the species under threat in the Neotropical region, particularly on endemic ones. Both the IRL and LRLs determined that habitat loss (agricultural use land than more 50%) is the most critical threat of arthropod diversity in this region, but other main threats were also found. The conservation efforts for arthropods in Neotropical countries have been developed heterogeneously. Special efforts are necessary to countries without red lists as large countries, islands, or island-like bioregions. So far, the most threatened arthropod diversity in the Neotropical region belongs to the Caribbean islands. Insect conservation is not just about red-listing. It is also crucial to conduct conservation action as habitat management and restoration, citizen science or specific policy to fight the illegal trade. The integration of LRLs with the IRL helped identify common threats to arthropod conservation and also facilitated the macroscopic evaluation of this topic. It is crucial to conserve Neotropical arthropods to protect animal biodiversity.

Implications for insect conservation The homologation of the LRLs in the IUCN would increase the representation of endemic arthropods generating (1) an increase in funding for research and (2) for local conservation policies such as ecological restoration, and their use as bioindicators of environmental impact on investment projects in agriculture, mining, forestry, and urbanization.

Keywords Araneae · Coleoptera · Habitat loss · Lepidoptera · Red list · Overexploitation · Tourism

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Introduction

Long-term projections have predicted that many species could become extinct in the future (Pimm and Brooks 2000; Thomas et al. 2004; Dirzo et al. 2014). The increase in extinction risk includes many anthropogenic factors, such as habitat loss, climate change, overexploitation, pollution, and the interplay among them (Brook et al. 2008; Dirzo et al. 2014; Bonebrake et al. 2019). Many of these assessments and extinction risk analyses have been extensively performed on charismatic vertebrates such as mammals, birds, amphibians, or vascular plants (Owens and Bennett 2000; Wake and Vredenburg 2008; Pimm et al. 2014; Ceballos et al. 2015), though arthropod biodiversity is also threatened by similar anthropic factors in many parts of the world. Many authors have emphasized that land use changes, chemical and light pollution, invasive species and global warming between others are major drivers of arthropod decline (Keller and Largiadèr 2003; Courchamp et al. 2006; Huey et al. 2012; Dirzo et al. 2014; Jerez et al. 2015; Macgregor et al. 2015; Maxwell et al. 2016; Ceballos et al. 2017; Aizen et al. 2019; Cardoso et al. 2020), even causing modern insect extinctions and defaunation (Dunn 2005; Dirzo et al. 2014). Arthropods are the largest animal group (Mora et al. 2011; Stork et al. 2015), and their importance in the maintenance of ecosystems is undoubted. Arthropods are essential for all terrestrial ecosystems because they realize pollination, dung burial, biological control, nutrient recycling, and cultural services (Cardoso et al. 2011b; Leather 2015; IPBES 2016; Traveset et al. 2017). However, conservation efforts for arthropods are still scarce, even though their decline worldwide has been conspicuous and widely advertised in many ways and taxonomic groups (Hochkirch 2016; Baur et al. 2020; Bell et al. 2020; Hallman et al. 2020; Roth et al. 2020). Therefore, an overview of the potential gaps in knowledge regarding the conservation status of arthropods is necessary to identify common extinction risk patterns.

Based on the available literature on insects, Sánchez-Bayo and Wyckhuys (2019) recently reviewed the worldwide decline of entomofauna and its drivers. The authors concluded that dramatic decline rates may lead to the extinction of the world's insect species over the next few decades. Terrestrial and aquatic insects, both specialists and generalist species, are affected by habitat loss, pollution, pathogens, invasive species, and climate change (Sánchez-Bayo and Wyckhuys 2019). However, this study showed an important gap in knowledge about arthropod conservation and its threats to the most biodiverse area of the planet: the Neotropical region. Sánchez-Bayo and Wyckhuys (2019) considered Puerto Rico, Costa Rica, and Brazil, excluding approximately 86% of the countries in the Neotropical region. Consequently, although Neotropical countries possess important biodiversity hotspots (Myers et al. 2000; Barboza and Defeo 2015) and mega-diverse countries as Colombia, we have little information about the patterns of Neotropical arthropod species and their potential drivers of decline.

The International Union for Conservation of Nature Red List of Threatened Species (IUCN Red List; henceforth, IRL) has provided criteria for assigning threat statuses to all the biota on the planet over the last 40 years (Rodrigues et al. 2006), which has an almost constant updating policy of their database. The IUCN criteria are useful tools that provide information about extinction risk; they are used to compare taxonomic groups, habitats, countries, and regions (Abellán et al. 2005; Juslén et al. 2013; Maes et al. 2019). Alternatively, local red lists (also called national or regional red lists; henceforth LRLs) can also be used to assess biodiversity and provide complementary information to make key conservation decisions and national policies (Rodrigues et al. 2006; Miller et al. 2007; Bachman et al. 2018; Govorushko and Nowicki 2019), although these red lists are often not updated. Comparisons between the IRL and LRLs are scarce in the literature (Brito et al. 2010). In fact, 20% of the species assessed as threatened by LRLs have not been globally assessed for the IUCN Red List, and 14% of the species evaluated by IRL have not been assessed in countries where these species live (Brito et al. 2010). This decoupling between lists makes it difficult to understand the conservation problems of a region or taxon.

Due to the absence of patterns that show the current conservation status of arthropods in the Neotropical region, we offer an overview of this topic. In this work, we compare the available data on arthropod species by determining the proportion of threatened species IUCN category (i.e. VU, EN and CR) per taxon and country using the lists of arthropods assessed by the IRL and LRLs in each Neotropical country. Both lists could provide complementary information in the extinction risks or threats for Neotropical arthropods. To test whether there are biases in the classification of taxonomic groups in both lists, we propose that (1) the number of arthropod species categorized in the LRLs are higher than those proposed by IRL and (2) that the threats-governing threatened arthropod species are similar in IRL and LRLs. Furthermore, (3) the relationship between the threatened and assessed species in the different conservation categories, and the total area of each country in the Neotropical region would be greater in those small countries with high endemism than in large countries with low endemism.

Material and methods

IUCN and local red list datasets

We used two main datasets to obtain the total number of arthropod species assessed under a threat category in each Neotropical country: (A) threatened species assessed under the IRL Criteria from 2006 to 2019 (IUCN 2012a), and (B) threatened species assessed under the LRLs for each Neotropical country up to 2019 and adopting the IRL criteria at the regional and national levels (IUCN 2012b). Some countries, such as Mexico, also have red lists at the subregional level (e.g. the red book of Veracruz) that use a system similar to that of the IUCN and, therefore, were considered LRLs. In addition, some official red lists or national prohibited hunting laws in some countries, such as Belize, Chile, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, and Panamá were not considered because they did not apply the IUCN criteria (Brenes et al. 1999; SAG 2015) and cannot be compared. Other countries not present LRLs with IUCN criteria or similar. For both IRL and LRLs, the arthropods assessed were proposed by entomologists and conservation biologists based on the information available and experience on the different taxonomic groups in each country. To compare both list types, we used the land regions characterized by the IUCN and those that belong to Neotropical countries: Caribbean islands ($n = 29$), Mesoamerica ($n = 8$), and South America ($n = 14$). The Caribbean islands that belong to another country, such as the Virgin Islands, Falkland (or Malvinas) or Guadeloupe, were considered independent units in this study for the search of red lists and their subsequent analyses. Additionally, islands that are administratively shared between two countries, such as the Virgin Islands (USA/UK) or Saint Martin (France/Netherlands) were considered independent.

For the IRL, we first filtered the threatened species available by taxonomy using the (1) Insect, (2) Arachnid, (3) Diplopod, and (4) Chilopod groups. Second, we only considered the Vulnerable (VU), Endangered (EN), and Critically Endangered (CR) groups because these are the taxa that currently need more attention. In addition, we separated endemic and native species. For each resulting filtered species, we obtained the threat(s) provided by IUCN, which were classified by (a) habitat loss, (b) pollution, (c) climate change, (d) invasive species, (e) overexploitation, and (f) tourism. To homogenize the criteria used to define threats by taxa between IRL and LRL, we used "habitat loss" when a particular species was classified by "residential & commercial development", "Agriculture & aquaculture", "Energy production & mining" and "Transportation & service corridors". We used the same criteria when using the word "tourism" when it was recreational and leisure-related activities that threatened the species. As each species can experience more than a single threat, we considered all possible causes described in the lists provided by the authors and, therefore, noted one or several threats. Finally, we identified the ecosystem type(s) that each assessed species inhabits. These were classified as (i) forest, (ii) aquatic ecosystems (iii) shrublands, (iv) grasslands, (v) desert, and (vi) caves.

For LRLs, we visit and consult official pages of the ministries of the environment (or similar), reports, red books, lists of species or documents related and we reviewed the assessed arthropods when the lists were available (Fig. 1). In each case, we reviewed whether government entities (e.g. local Ministry of the Environment) or researchers had adopted the IRL criteria and applied it at the regional or local level to assess arthropod species. We selected the same filters for the arthropod groups, threatened criteria,

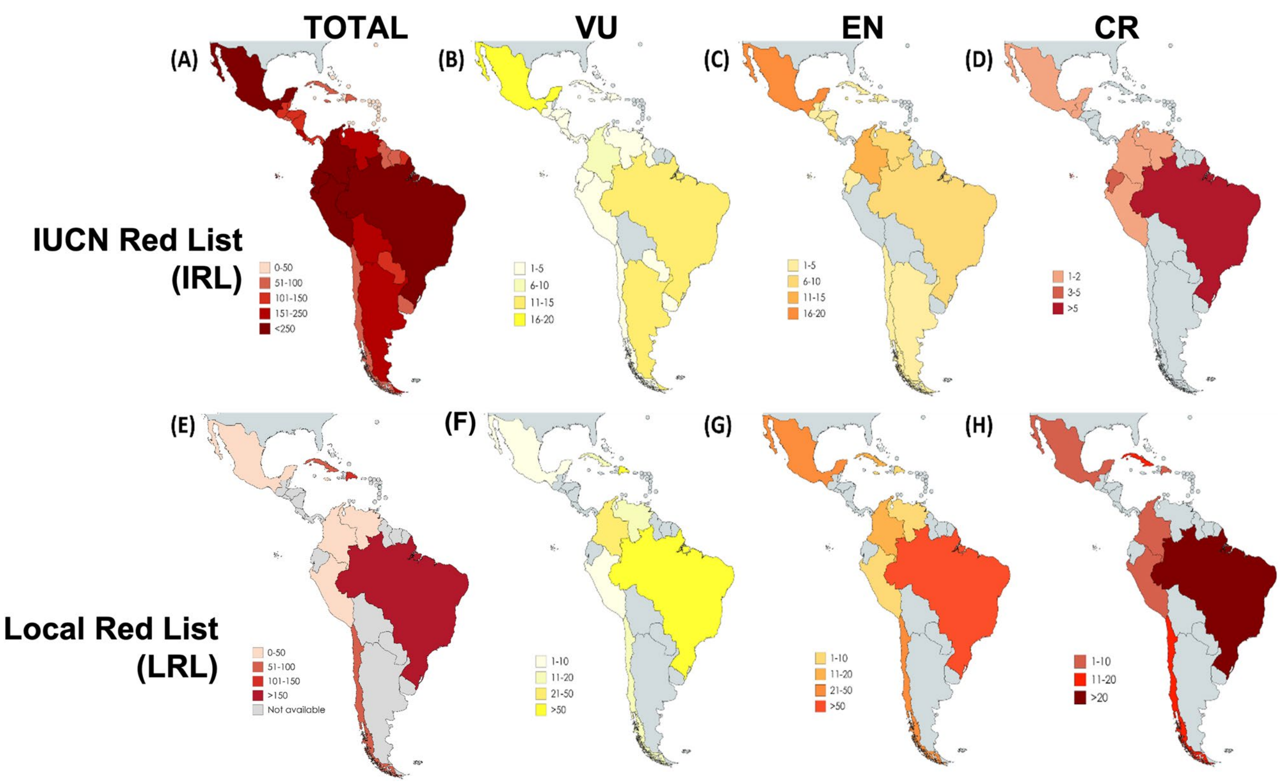

Fig. 1 Absolute number of total Neotropical assessed species under IRL (**A**) and LRL (**E**), including all criteria (i.e. from low concern to extinct); Vulnerable (VU) assessed species under IRL (**B**) and LRL (**F**); Endangered (EN) assessed species under IRL (**C**) and LRL (**G**); Critically Endangered (CR) assessed species under IRL (**D**) and LRL (**H**)

ecosystem type, and threats mentioned above. Endemic species were also categorized by the same system mentioned above. The LRL for Chile was obtained from the MMA (Ministerio del Medio Ambiente de Chile 2019); for Peru, from SERFOR (2018); for Brazil, from 'Livro Vermelho da fauna Brasileira Ameaçada de Extinção' of the Instituto Chico Mendes de Conservação da Biodiversidad (2018; henceforth, ICM); for Colombia, from Amat-García et al. (2007); for Venezuela, from Rodriguez et al. (2015); for Jamaica, from the national Wildlife Act (2017); for Dominican Republic, from the Ministerio del Medio Ambiente y Recursos Naturales (2018); for Cuba, from Hidalgo-Gato et al. (2016), and for Veracruz state in Mexico, the red book of threatened arthropod species by Hernández-Baz and Rodríguez-Vargas (2014; Fig. 1).

To determine whether there were significant differences between the taxonomic groups assessed by the IRL or LRLs, we tested whether the number of species classified under the conservation categories and the total number of classified species were distinct between both red list types. To test this, we used a chi-square test for the given probabilities using R software (R Core Team 2019). We only used taxonomic groups with representation in both list types (i.e. Araneae, Coleoptera, Hymenoptera, Lepidoptera, Odonata, and Orthoptera). The total minimum value used for comparisons (i.e. the sum of all conservation categories for different taxonomic groups) was five.

Threatened species per country area

To determine the countries that have the highest proportions of threatened arthropods, given the area of each country, we proposed a simple index that considers the correction by area. For this, we first considered that the threat categories (CR, EN, and VU) have different levels of importance and, therefore, we assigned values to each of these categories. We used numerical values (NVs) for each species assessed by country (i) and assigned them the values that the IUCN proposed as thresholds for the different threat categories. These values were as follows: 80 for CR (> 80% decrease = critically endangered); 50 for EN (> 50% decrease = endangered), and 30 for VU (> 30% decrease = vulnerable; IUCN 2012a, b; Maes et al. 2019). The sum of the NVs was posteriorly corrected for the geographical area of each country, but to smooth the spatial differences between each country, we used the square root of each area. Then, we generated the Threat per Area index (TpA) as follows:

$$\mathrm{TpA} = \frac{\sum (NVi)}{\sqrt{(area)}}$$

This index assumes values ranging from $0 \rightarrow \infty$, where the higher values represent the countries with the highest proportions of threatened arthropods per area. Therefore, this index will be higher in countries with a high number of threatened species and a small area than in countries with a low or similar number of threatened species but a large area. Countries with fewer than three of the species assessed were excluded.

Results

IUCN red list

Of the 1303 assessed Neotropical species in the IRL up to 2019, only 154 (11.81%) species were classified in any threat category: VU = 65, EN = 66, and CR = 23 (Fig. 1A–D; Table 1; Supplementary Table S1). South American countries had the highest number of arthropod species classified under a threat category ($n = 91$), followed by Mesoamerica ($n = 47$) and the Caribbean Islands ($n = 15$; Fig. 1). The most represented insect order in all threat categories (i.e., VU, EN and CR) was Odonata ($n = 75$; 49.01%), followed by Hymenoptera ($n = 25$; 16.33%) and Coleoptera ($n = 17$; 11.11%) (Fig. 2A). These assessed groups are strongly influenced by IUCN SSC specialist groups. The species assessed under a threat category were mainly endemic ($n = 139$), with Brazil being the most numerous ($n = 35$; 25.17%), followed by Colombia and Mexico, both with 21 endemic species, or 15.11%, each (Fig. 2B). According to the IRL, habitat loss ($n = 118$; 73.69%) due to land use change, climate change ($n = 25$; 15.52%), and invasive species ($n = 24$; 14.90%) were the greatest threats for Neotropical arthropod biodiversity (Fig. 3A, B). Agriculture, urbanization, and wood harvesting affected 60 (50.84%), 56 (47.45%), and 54 (45.76%) of the total species, respectively, representing the most common land cover changes that impact Neotropical arthropods. Based on this, forests ($n = 90$; 55.90%) and aquatic ($n = 67$; 41.61%) were the most threatened Neotropical ecosystems (Fig. 3B).

Local red list

Of the 2862 assessed species under LRL levels up to 2019, only 573 (20.02%) species were classified in any threat category: VU = 239, EN = 203, and CR = 131 (Fig. 1E–H; Table 1, Supplementary Table S2). South American countries had the highest number of arthropod species assessed under a threat category ($n = 392$), followed by the Caribbean Islands ($n = 153$) and Mesoamerica ($n = 31$; Supplementary Table S3). The most assessed arthropod orders were Lepidoptera ($n = 186$; 32.46%), Coleoptera ($n = 107$; 18.67%), Hymenoptera ($n = 51$;

Table 1 Absolute number of species assessed per taxa using IUCN Red List (IRL) and Local Red Lists (LRLs) categories

Taxa	IUCN Red Lists (IRLs)				Local Red Lists (LRLs)			
	VU	EN	CR	total	VU	EN	CR	Total
Acari	0	0	0	0	3	0	4	7
Amblypigi	0	0	0	0	4	3	2	9
Araneae	2	3	0	5	7	12	13	32
Blattodea	0	0	0	0	2	0	0	2
Chelipoda + Diplopoda	0	0	0	0	8	4	5	17
Coleoptera	8	9	0	17	42	48	17	107
Collembola	0	0	0	0	1	2	10	15
Diptera	1	0	0	1	6	3	1	10
Ephemeroptera	0	0	0	0	7	2	0	0
Hemiptera	0	0	0	0	9	1	0	10
Hymenoptera	18	5	2	25	18	18	15	51
Lepidoptera	6	8	1	15	60	86	40	186
Odonata	19	37	19	75	17	9	3	29
Opiliones	0	0	0	0	0	5	4	9
Orthoptera	11	4	0	15	20	0	2	22
Palpigradi	0	0	0	0	1	2	4	7
Phasmidae	0	0	1	1	1	0	0	1
Plecoptera	0	0	0	0	0	1	1	2
Pseudoescorpiones	0	0	0	0	1	2	7	10
Schizomida	0	0	0	0	10	0	1	11
Scorpiones	0	0	0	0	20	5	2	27
Solifugae	0	0	0	0	2	0	0	2
Total	65	66	23	154	239	203	131	573

CR critically endangered, *EN* endangered, *VU* vulnerable

8.90%), and Araneae ($n=32$; 5.58%) (Fig. 2A; Supplementary Table S3). The threatened species were mostly endemic or rare, with a narrow range and/or few records ($n=501$; 87.58%), with Brazil being the most numerous ($n=208$; 36.36%), followed by the Dominican Republic ($n=91$; 15.09%), Venezuela ($n=53$; 9.26%), and Cuba and Chile (both with $n=48$ and 8.39%; Fig. 2B). Additionally, Lepidoptera was the most classified insect group under threat categories in Brazil, Dominican Republic, Venezuela, and Cuba (Fig. 4A, B, D, and E). In addition, Theraphosidae, Coleoptera, and Hymenoptera were the other highly classified species under conservation categories in Brazil (Fig. 4A); Coleoptera and Diptera were the main taxonomic groups assessed under threat categories in Chile (Fig. 4C); Orthoptera was the secondary classified taxonomic group under threat categories in the Dominican Republic (Fig. 4B), and Hymenoptera was the second most assessed insect order under threat categories in Cuba and Colombia, respectively (Fig. 4E and F; Supplementary Table S3). On the other hand, habitat loss ($n=449$; 78.49%) driver by wood harvesting (n = 119; 26.50%), urbanization (n = 90; 20.04%), mining and cattle (n = 49; 10.91% each) or croplands (n = 129; 28.73%); overexploitation ($n=73$, 12.76%), and tourism ($n=66$; 11.53%) were the most reported threats by the LRLs (Fig. 3A). Forests ($n=300$; 52.44%) and caves ($n=86$; 15.0 1%) were the most threatened Neotropical ecosystems (Fig. 3B).

Common threats between the IRL and LRLs

Overall, the results suggest that there are common threats, irrespective of the red list type. For instance, 97.90% ($n=560$) of the taxa considered in this study are threatened by habitat loss. Lepidoptera (31.79%), Coleoptera (20%), and Odonata (15.18%) are the orders most linked to this threat. Secondarily, tourism affected 11.36% of the groups, mainly Coleoptera (23.08%) and Collembola (18.46%). Finally, 10.83% of the taxonomic groups are threatened by overexploitation, and Coleoptera (56.45%) and Araneae (20.97%) are the most affected groups. The invasive species, pollution, and climate change have been less linked as threats. Coleoptera and Lepidoptera were the most affected by sinergistic threats (> 10% of species), jeopardized by 5 out of 6 threats each, followed by Araneae, Hymenoptera and Odonata (2 out of 6) (see Fig. 5; all values in Supplementary Table S4). Only 5.76% ($n=33$) of species classified under a threat category were shared between both list types, with Brazil having the most shared species

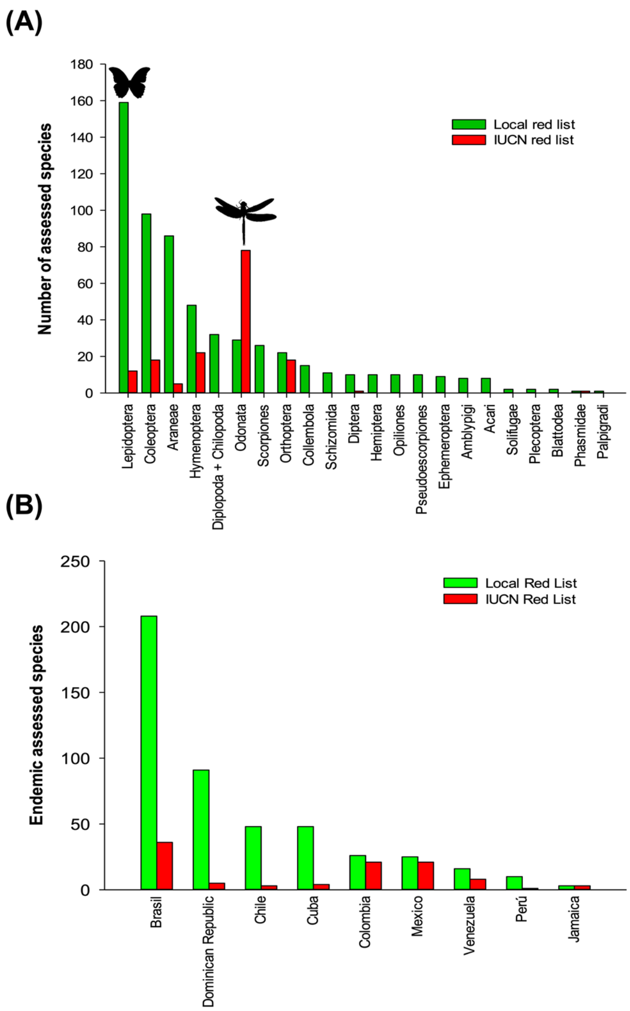

Fig. 2 **A** Number of arthropod threatened species (i.e. VU, EN and CR) by the IRL and LRL in Neotropical region. **B** Number of endemic assessed species by the IRL and LRL in Neotropical region

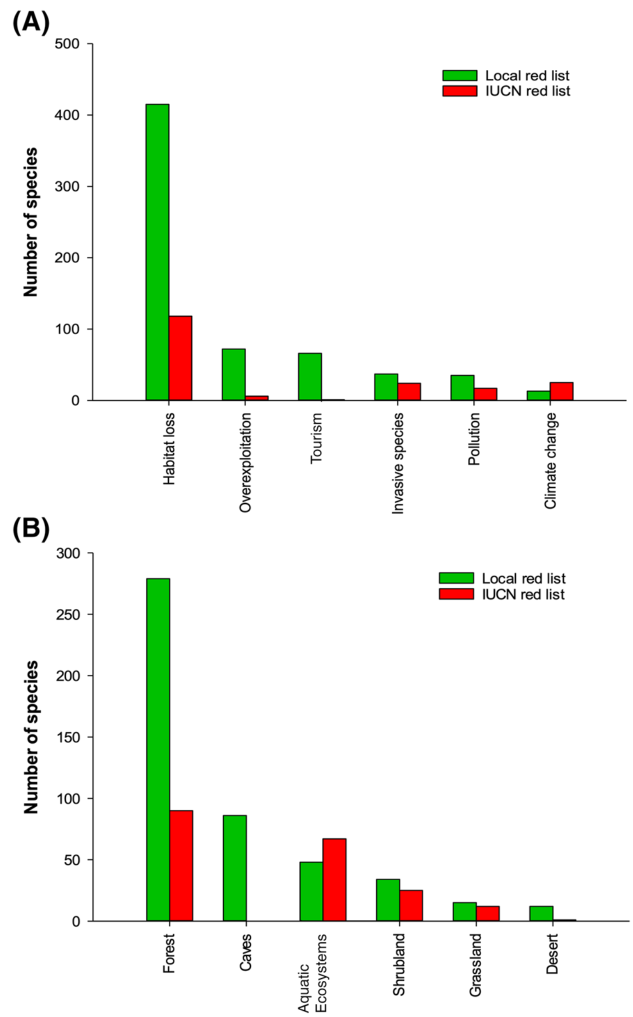

Fig. 3 **A** Number of threatened species per different drivers by IRL and LRL; **B** Number of threatened species per different ecosystems by UICN and local red list;

($n = 16$), followed by Venezuela ($n = 6$), Dominican Republic ($n = 4$), and Chile and Jamaica with only three species each (Fig. 6). We found statistically significant differences among the threat categories (i.e., VU, EN, or CR) and taxonomic groups classified by the IRL and LRLs. Lepidoptera, Coleoptera, and Araneae were classified as more threatened by the LRLs than by the IRL. Hymenoptera also presented statistically significant differences, but the IRL had more threatened species, except in the vulnerable category, where there were no statistically significant differences. Finally, Orthoptera did not show differences between the IRL and LRLs (further detail in Table 2).

Threatened species per country area index

The countries with the highest proportions of threatened arthropods per area were headed by the Dominican Republic (17.76), followed by Cuba (7.93), and the Cayman Islands (6.77). However, excluding the Caribbean Islands with small areas, countries with large areas and above-average index values (3.28) were Brazil (4.71) and Chile (3.45). Small countries such as Honduras (0.32) and Nicaragua (0.3), as well as large countries, such as Argentina (0.29) and Peru (0.67), that are well below average, even when we remove the outlier value of the Dominican Republic (further details see Table 3; Fig. 7).

Discussion

Red lists

Arthropods currently classified by the IUCN Red List are > 1% ($n = 10{,}105$) of all arthropod species described

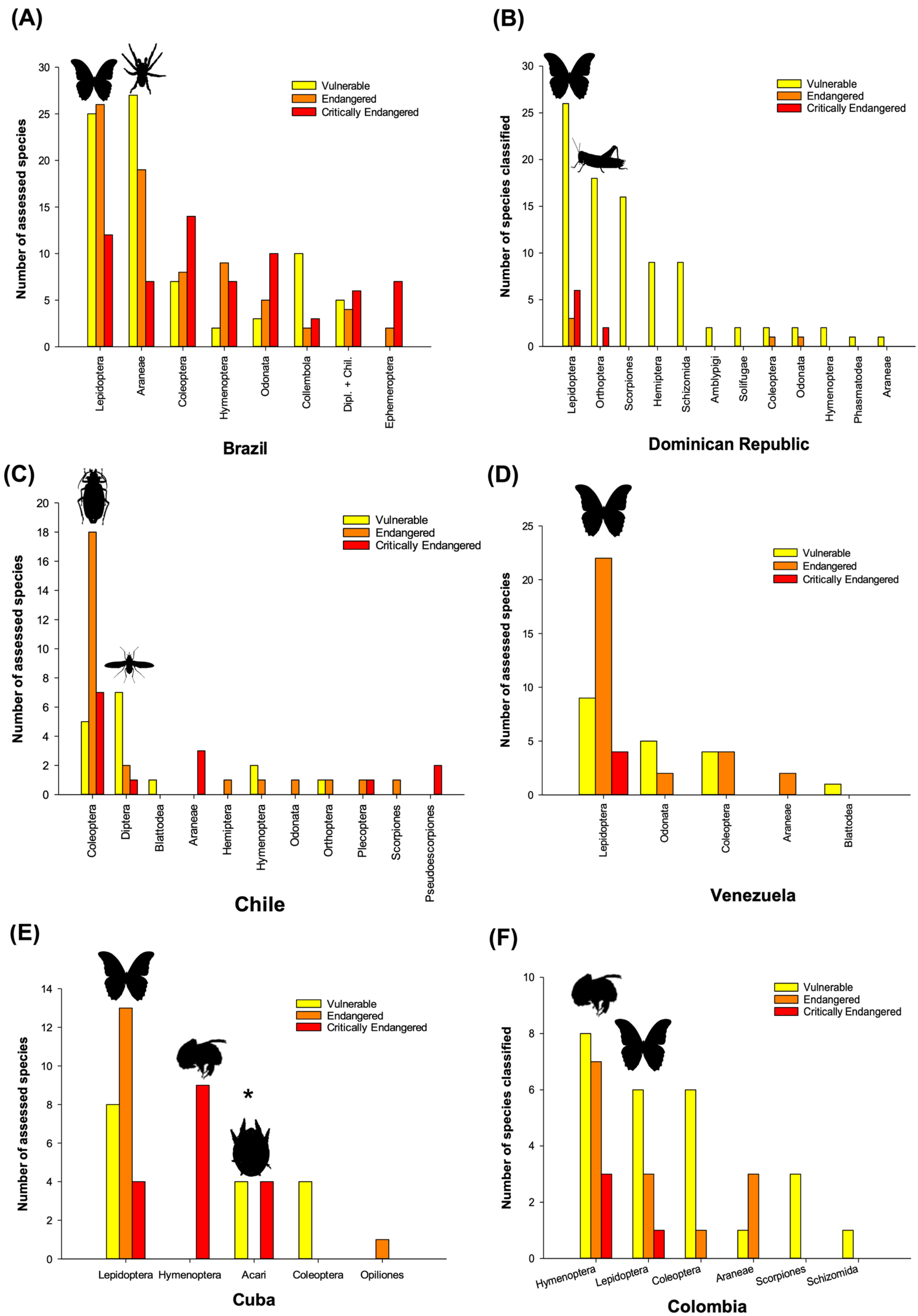

Fig. 4 Number of threatened arthropod species at different conservation categories by LRL in most representative Neotropical countries: **A** Brazil; **B** Dominican Republic; **C** Chile; **D** Venezuela; **E** Cuba and **F** Colombia. (*) not includes extinct species

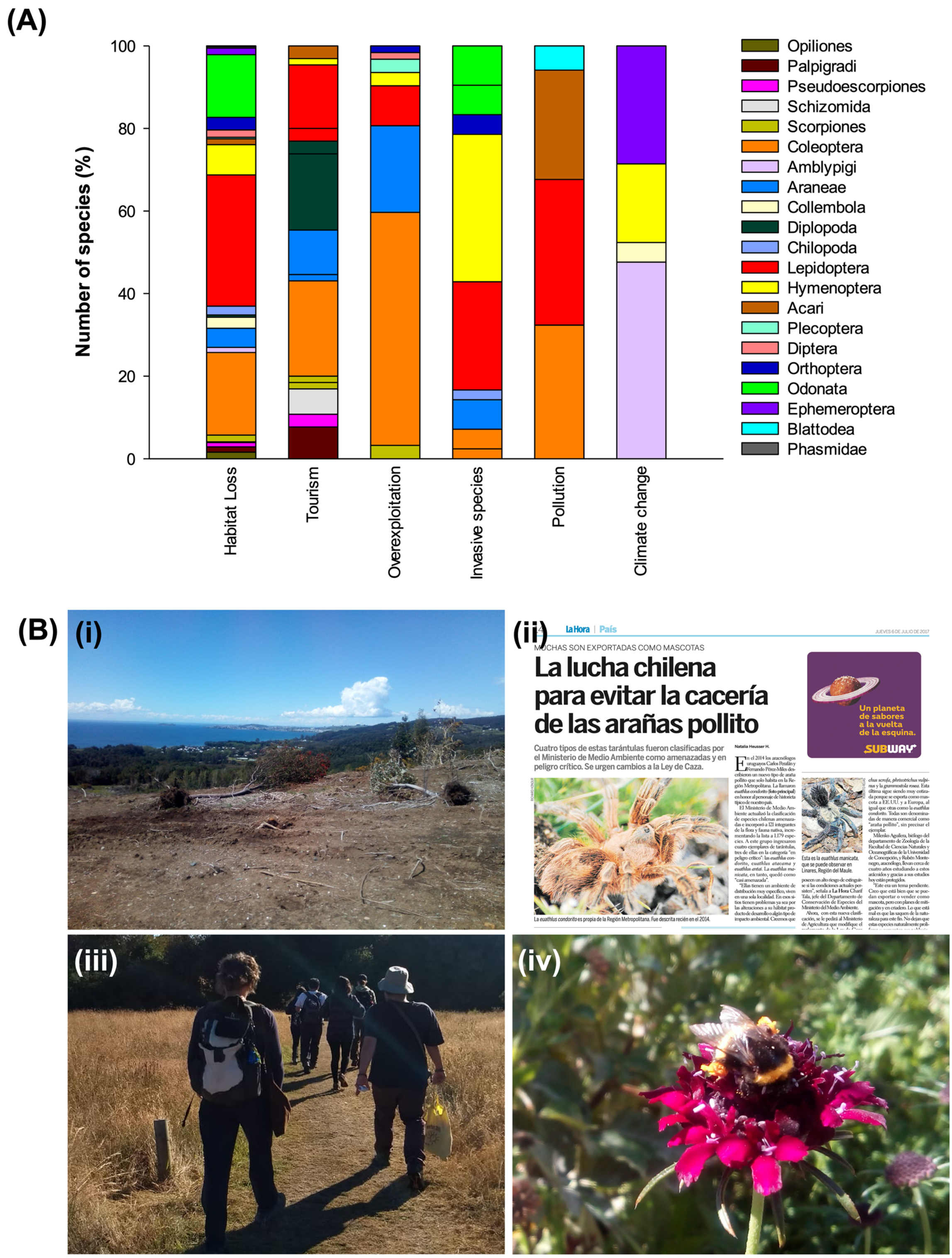

Fig. 5 **A** Cumulative percentage per taxonomic group of assessed species by different threats reported in Neotropical region; **B** Main threats for arthropods biodiversity in Neotropical Region: (i) Valdivian forest clearing for semi-rural urbanization, Ancud, Chiloé, Chile; (ii) tarantula trade news in Chile by Ruben Montenegro and Milenko Aguilera; (iii) deregulated tourism and (iv) invasive species represented by *Bombus terrestris*, an exotic and invasive species present in Chile and Argentina (Aizen et al. 2019)

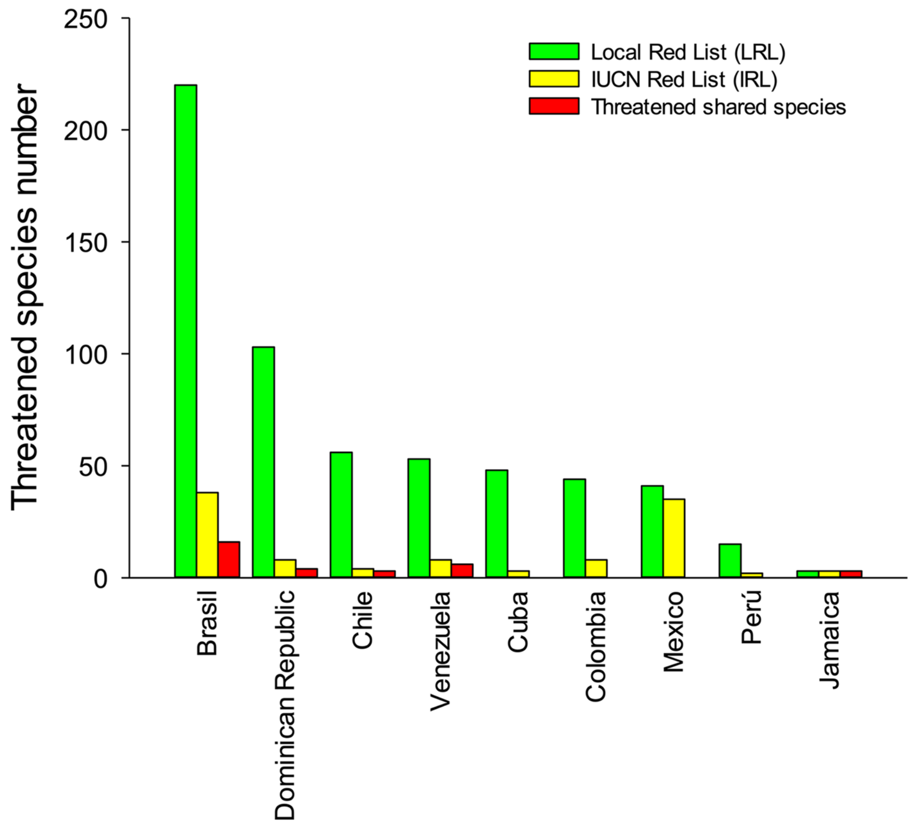

Fig. 6 Number of threatened arthropod shared between IRL and LRL

(Eggleton 2020), and this reflects the obstacle that we face with their conservation (Hochkirch et al. 2020). Additionally, the proportions of Neotropical threatened species based on the LRLs (i.e. 19.98%) are close to the average percentage of declining species reported by Sánchez-Bayo and Wyckhuys (2019) in different biogeographical regions (23%). Although the IUCN Red List is the most useful international tool for extinction risk assessment worldwide, we found that LRLs provided significantly more arthropod assessments for each country, and this is particularly true for endemic components (LRLs = 472 vs. IRL = 139; Table 1). For this reason, LRLs have a great impact on local conservation policies (Brito et al. 2010; Cardoso et al. 2011a). For instance, the arthropods classified in threat categories in Chile are incorporated into national environmental impact assessments, and previous monitoring is required for public or private projects that may affect the ecosystems there.

The integration of invertebrate LRLs into the global assessment of the IUCN has been proposed by several authors (Cardoso et al. 2011a; van Swaay et al. 2011; Maes et al. 2019). In this paper, we propose that the IRL homologates these assessments of Neotropical arthropods for three main reasons: (1) LRLs represent a unique opportunity to assess endemic species, improving the representativeness of small countries, especially the Caribbean islands, and increasing the representation of threatened species from the Neotropical region by up to 300% in the IRL; (2) LRLs have a greater diversity of taxa that are not represented in the IRL for the Neotropical region, such as Schizomida, Opiliones, Amblypigi, Scorpiones, Chilopoda, and Diptera, which represent 22.78% ($n = 121$) of our results; (3) we found a low percentage (5.76%; $n = 33$) of threatened species that are shared between both red list types, which is consistent with the findings of Brito et al. (2010). The IUCN Red List is a powerful tool for assigning extinction risk probabilities to all the biota on the planet (Rodrigues et al. 2006), and it also provides possibilities to raise awareness of the silent extinction processes of many arthropod species. The threatened species that were identified under the LRLs have been evaluated from the adapted IRL at the national or regional level (see Hidalgo-Gato et al. 2016; ICM 2018; Ministerio del Medio Ambiente y Recursos Naturales 2018; SERFOR 2018; MMA 2019). In many cases, the information obtained from the LRLs is of adequate quality to be considered by the IRL, in particular for arthropods and for all living organisms in general. Research in arthropods conservation is largely non-financed (Cardoso et al. 2011a; Hochkirch et al. 2020), and studies on species in the IRL can receive special funding, which can support research on understudied arthropods. This could be an important consequence of homologating the red lists. Moreover, funding agencies or companies that depend on invertebrates' services should use national lists to

Table 2 Chi-square test for differences in classified species under the vulnerable (VU), endangered (EN), and critically endangered (CR) categories among the International Union for Nature Conservation Red List (IRL) and Local Red List (LRL) criteria by taxonomic group (Order). Significant values ($p < 0.05$) in categories or total per order in bold

Order	Category	IRL	LRL	df	χ^2	*p* value
Coleoptera	VU	8	42	1	23.12	**< 0.0001**
	EN	9	48	1	26.68	**< 0.0001**
	CR	0	17	1	17.00	**0.0001**
	Total	17	106	1	64.40	**< 0.0001**
Lepidoptera	VU	6	60	1	44.18	**< 0.0001**
	EN	8	86	1	64.72	**< 0.0001**
	CR	1	40	1	37.10	**< 0.0001**
	Total	15	186	1	145.48	**< 0.0001**
Orthoptera	VU	11	20	1	2.61	0.2888
	EN	4	0	NA	NA	NA
	CR	0	2	NA	NA	NA
	Total	15	22	1	1.32	0.5271
Arachnida*	VU	2	48	1	42.32	**0.0027**
	EN	3	27	1	19.20	**< 0.0001**
	CR	0	37	1	37.00	**< 0.0001**
	Total	5	112	1	97.86	**< 0.0001**
Odonata	VU	19	17	1	0.11	0.7389
	EN	37	9	1	17.04	**0.0410**
	CR	19	3	1	13.76	**0.0010**
	Total	75	29	1	20.35	**< 0.0001**
Hymenoptera	VU	18	18	1	0.00	1.0000
	EN	5	18	1	7.34	**0.0067**
	CR	2	15	1	9.94	**0.0016**
	Total	25	51	1	8.89	**0.0028**

NA not applicable due to insufficient data

*Includes Schizomida, Amblypigi, Pseudoescorpiones, Opiliones, Palpigradi, Acari, and Solifugae

Table 3 Number of arthropods assessed by the Union for Nature Conservation Red List (IRL) and Local Red List (LRL) together per conservation categories, total number of threatened species, area per country, and Threat per Area (TpA) per country

Country	CR	EN	VU	TOTAL	AREA	TpA
Dominican Republic	8	9	94	111	48,442	17.76
Cuba	17	14	19	50	109,884	7.93
Cayman Island	0	1	2	3	264.2	6.77
Brazil	95	78	75	248	8,515,770	4.71
Chile	14	28	16	58	756,950	3.44
Venezuela	4	31	19	53	916,445	2.54
Costa Rica	0	10	2	12	51,100	2.47
Colombia	6	25	30	61	1,142,748	2.46
México	2	45	19	66	1,964,375	2.12
Jamaica	0	2	1	3	10,992	1.24
Guatemala	1	3	4	8	108,888	1.06
Ecuador	3	4	1	8	283,560	0.88
El Salvador	0	1	2	3	21,041	0.75
Peru	3	5	9	17	1,285,220	0.67
Honduras	0	1	2	3	112,492	0.32
Nicaragua	0	1	2	3	130,000	0.30
Argentina	0	2	13	15	2,780,400	0.29

Repeated assessed species were discounted per country. Countries were ordered from high to low TpA values and countries with fewer than three threatened species were not presented

CR critically endangered, *EN* endangered, *VU* vulnerable

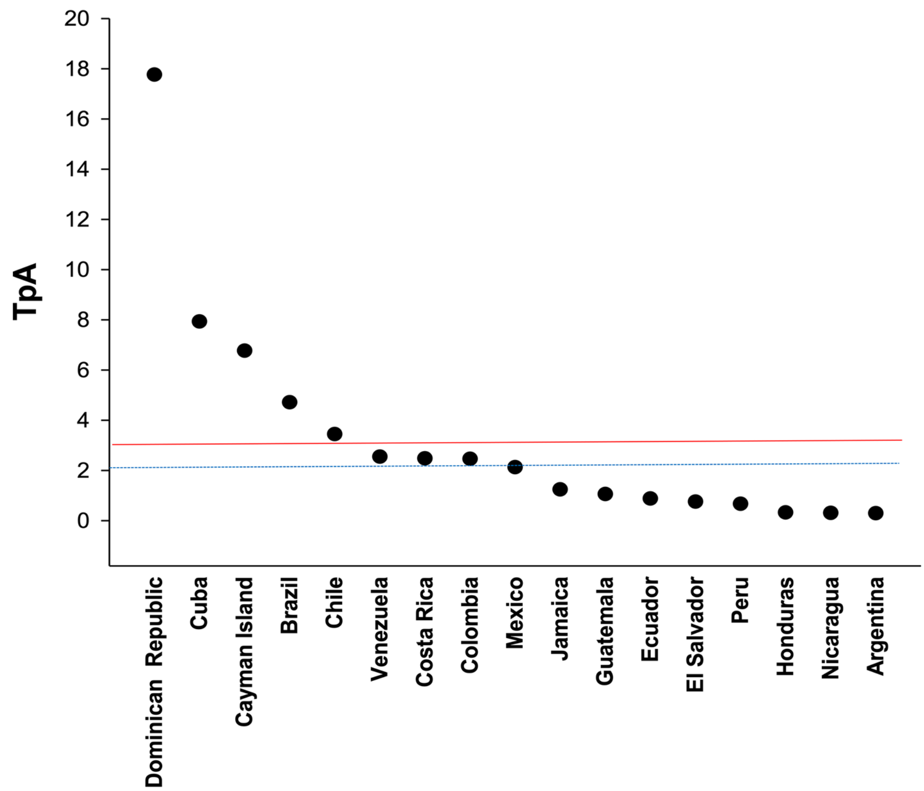

Fig. 7 Threat per Area index (TpA) per country. Horizontal red line represent mean TpA value with all data; horizontal dashed blue line represent mean TpA without Republican Dominican

prioritize research funding (Hochkirch et al. 2020). On the other hand, most of the databases used for technical reports in LRL are not freely available, which could interfere with the integration of both red lists. This information is key to submit endemic arthropod datasets into IUCN Species Information Service (SIS connect), a systematized web application for conducting and managing species assessments for IUCN and thus, increase the species number classified in the Neotropical Region.

Overall, we do not have the necessary knowledge to fit arthropods in the Red List categories for most species according to Cardoso et al. (2011a). The lack of basic ecology information, especially its geographical distribution, is the most important shortfall that impedes species meet Red List thresholds and categories, and prioritizing conservation efforts turns ineffective. On the other hand, it is also necessary to put attention to species classified as least concern (LC), which have a large extent of occurrence, or deficient data (DD), which have a deficit in knowledge about their distribution or abundance. To detect negative effects of human activities on LC or DD species, it is essential to use spatial tools or distribution models that allow obtaining data, for example, on habitat loss and fragmentation. For example, *Aneriophora aureorufa*, a native fly species of Chile and Argentina, is a forest specialist that has lost 68% of its historical habitat but has been classified by the Chilean Ministry of the Environment as LC due to its wide distribution (Barahona-Segovia et al. 2016; Alaniz et al. 2018).

Threats and ecosystems

Alarming losses in natural areas (3.3. million km^2) are currently occurring around the world, especially in Amazonian (30%) and central African (14%) tropical forests (Watson et al. 2016), while other authors (Lambin and Meyfroidt 2011) have reported that 37% of the world's natural biomes have been transformed into grasslands (23%), croplands (12%), or urbanized areas (2%). Our results are in concordance with Sánchez-Bayo and Wyckhyus (2019), Cardoso et al. (2020) and Wagner (2020), where habitat loss is the main threat to Neotropical arthropods, impacting over 90% of threatened species. Forests and aquatic ecosystems were the most affected by agriculture, urbanization, forestry, and mining, according to our results (Fig. 3B). However, the impact of habitat loss seems to be a species-dependent type. Some terrestrial insects, such as primary forest butterflies, are more sensitive to the expansion of agricultural frontiers and loss of their symbiotic plants than grassland species, which could be even favoured (see Rodríguez et al. 2015; Hidalgo-Gato et al. 2016; Ministerio del Medio Ambiente y Recursos Naturales 2018). On the other hand, aquatic insects, such as Odonata, are sensitive when wetlands, streams, or rivers are replaced or dried up (Clausnitzer et al.

2009). In addition, almost all Neotropical taxonomic groups had two or more threats interacting among them, as suggested by Brook et al. (2008).

In this study, tourism and overexploitation appeared as secondary threats for Neotropical arthropods, which were inconsistent with the findings of other authors (Sánchez-Bayo and Wyckhuys 2019; Eggleton 2020; Wagner 2020). Businesses aimed at satisfying the desires of many hobbyists, collectors, or pet lovers are flourishing and account for 90.32% of large or colorful Neotropical arthropods (see examples in Amat-García et al. 2007; ICM 2018; SERFOR 2018; Barahona-Segovia 2019; Law 2019; MMA 2019) or even on small and inconspicuous species (Crespin and Barahona-Segovia 2021). In addition, these unregulated practices in ecosystems that are already impacted by habitat loss can lead to biopiracy for rare and threatened species with an uncertain negative impact on the remaining individuals (Courchamp et al. 2006; Fukushima et al. 2020; Crespin and Barahona-Segovia 2021). The collection of arthropods has historically been a nice and educational hobby that should be done with environmental responsibility; it has been even useful for citizen science programs (see an example in Kelemen-Finan et al. 2018). On the other hand, tourism is considered the third most important driver in the decline of Neotropical arthropods, especially troglobitic species because tours may not have considered the necessary safeguards for biota protection added to other human activities (Simões et al. 2014), especially in countries such as Brazil, Peru, and Venezuela. However, other human activities also strongly impact highly vulnerable ecosystems; the real estate market, recreational activities, and light pollution on beaches, dunes, or ammophilous ecosystems all impact Neotropical arthropods, which are absent from Neotropical red lists (González et al. 2014; Jerez et al. 2015; Seer et al. 2015; Luarte et al. 2016). Perhaps these secondary effects are not dangerous by themselves or with adequate sustainability programs, but in combination with habitat loss, they can be problematic for endemic and restricted Neotropical arthropods.

Moreover, other ecosystems that are equally threatened by human activities are underrepresented, particularly highlands, hyperarid or cryogenic ecosystems. These have extremophile taxa that require singular environmental conditions. Arthropods, such as *Andiperla willinki*, which inhabits the Patagonian icefield (Plecoptera; see Vera et al. 2012), and *Maindronia neotropicalis*, which inhabits the Atacama Desert core (Zygentoma; see Zúñiga-Reinoso and Predel 2019), are extremophiles animals that can only survive with specific food nets and environmental conditions, normally with narrow distributions and are highly susceptible to climate change. Therefore, we encourage entomologists and conservation biologists to assess arthropods from other impacted ecosystems, such as intertidal rocky shores, dunes and beaches, Brazilian Serrado, Atlantic and Chaco forest, Paramo or other Andes highlands. Concurrently, habitat loss and synergistic forces can affect nonrandom biological interactions produced by co-evolution and generate extinction cascades, which are major silent force in the decline of arthropod biodiversity (Rezende et al. 2007; Dunn et al. 2009; Cardoso et al. 2011b; Bulgarella and Palma 2017; Traveset et al. 2017). These interactions and their resilience to anthropic pressures represent a new challenge for arthropod conservation in many Neotropical countries, currently not considered by IUCN Red List.

Threatened species per country area

Although animals such as mammals, birds, reptiles and amphibians have clear patterns of richness, evolutionary distinctiveness and phylogenetic endemism through different latitudes and ecosystems in the Americas and 24.5% have a high risk of extinction in the medium-term future (Cavender-Bares et al. 2018), arthropods continue to be the animal group with the greatest knowledge deficit in these aspects (Hochkirch et al. 2020). For this reason, this index represents an easy and rapid tool to reveal gaps in terrestrial arthropod conservation in the Neotropical realm using a dataset of threat category species and standardization by country area. First, it can be used to detect countries (small and large) that performed poorly in arthropod species assessments based on conservation status. One of the most critical examples of this is Argentina because this country has a high total area and environmental heterogeneity but does not have an LRL, and the few species were assessed under the IRL. Second, it offers a better measure for buffering the area effect of a large country, highlighting the efforts of small countries in extinction risk assessments such as the Dominican Republic and Cuba. In the Caribbean Islands, endemic arthropods have a low area of occupancy, representing good models for rapid arthropod conservation assessments (see Cardoso et al. 2011b) in regions that are facing rapid changes in native habitats by human activities. Additionally, countries with larger areas, such as Brazil and Chile, also exhibited strong conservation efforts based on the extinction risk assessment compared to those of smaller countries. Cavender-Bares et al. (2018) provide status and trends of native biodiversity and threatened species due to human activities in the Americas for both terrestrial and aquatic ecosystems. Although ants, pollinators, or other arthropods are mentioned with specific examples, the absence of a systematic overview of threatened arthropods from the Neotropical region is justified and necessary, considering that they are an important piece in all ecosystem process. In this context, this index could also be applied at the regional or ecosystem level (e.g., counties or even municipalities), providing a more local overview of the requirements or planning for the conservation of arthropods. In fact, some countries could be underrepresented because the LRLs assessed many species from a particular ecosystem (e.g., Brazilian Atlantic forest or Central Chile) or particular regions, such as Veracruz in Mexico.

Conclusion

This is the first regional effort to unite all information from Neotropical countries and to understand the extinction risk patterns of their arthropods. This information can be taken as the baseline to prepare future studies in sensitive and priority areas based on threatened arthropod species. Although we know more about native, and/or conspicuous arthropod species, we encouraged the study of endemic, and inconspicuous arthropods to gain a better understanding of their conservation statuses. Many of them inhabit leaf litter, intertidal rocky shores, highlands, coastal dunes, and other sensitive ecosystems that are commonly impacted by croplands, urbanization, and wood harvesting, although other human activities are likely to impact them silently as well, such as trade and tourism (Cardoso et al. 2011b, 2020; Dirzo et al. 2014; Jerez et al. 2015; Barahona-Segovia 2019; Law 2019). Recently, Harvey et al. (2020) proposed a roadmap for the conservation and recovery of threatened insects. These authors proposed performing a large-scale assessment using the IRL criteria and encouraged new studies to understand the contributions of anthropogenic drivers on arthropod abundance and distributions. We call all the countries in the Neotropical region to evaluate the extinction risks of their endemic arthropod biota to understand their conservation statuses, particularly in countries with limited or no conservation efforts. This is completely necessary, not only because the information on invertebrates is poor, but also because arthropods are one of the major forces in the well-being of humans due to ecosystem services (Cardoso et al. 2011a, 2020; Leather 2015). Currently, the Neotropical region is losing arthropod diversity, mainly because of bad policy practices, which are based only on intensified extractivism and economic benefits, increasing ecosystem transformation in this region. Therefore, the integration of LRLs with the IRL in the region would make it easier to evaluate the global situation of the arthropod biota.

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