Received: 27 September 2023 | Revised: 27 January 2024 | Accepted: 2 February 2024

DOI: 10.1002/ppp3.10506

Plants People Planet PPP Open Access

RESEARCH ARTICLE

Diversity and conservation status of palms (Arecaceae) in two hotspots of biodiversity in Colombia and Ecuador

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Societal Impact Statement

Palms provide vital plant resources and ecosystem services to people across the tropics. To improve conservation guidance, a "health check" of palms in two highly threatened biodiversity hotspots in Colombia and Ecuador was undertaken. Palms are very diverse in these regions, but over one third are threatened with extinction now, especially among endemic species. Widespread and useful palms are also under intense human pressure and need to be prioritized in terms of sustainable management practices. Given the importance of palms for humans, inclusive conservation actions should be continued in both countries in order to safeguard this resource.

Summary

- Palms provide central plant resources to societies in the tropics, especially in the Global South. The western Pacific and Andean regions of Colombia and Ecuador host two hotspots of biodiversity. To prioritize conservation policies towards palms, we undertook a conservation assessment of species in the region.
- We compiled a taxonomically verified database of specimens collected in both hotspots. We inferred preliminary conservation assessments using International Union for Conservation of Nature (IUCN) Criteria B. In addition, we evaluated the level of exposure of palms to human use and population density using the anthrome concept.
- We documented 144 native palm species in 33 genera occurring in both hotspots of Colombia and Ecuador. Of these, 55 are endemic to this region. We recorded 133 species for Colombia, 43 endemic, and 71 species for Ecuador, 9 endemic. A third of all palm species in the region are potentially threatened with extinction (50/144) and 12 as preliminary Critically Endangered. *Aiphanes* and *Geonoma* have the highest number of threatened species. In total, 60% of palm specimens were

Thomas L. P. Couvreur and Nayeli Jijon contributed equally to this work.

Funding information
H2020 European Research Council, Grant/Award Number: 865787; IUCN SSC Internal Grant, Grant/Award Number: SMA-G00-00214

collected in the "low human impact" anthrome type. In contrast, 41% of specimens occur in high human density areas.

- The two hotspots of biodiversity in Colombia and Ecuador are very diverse in palms. However, we show that this diversity is under threat and is predominantly found in areas impacted by human activities. Extinction risk is highest in endemic species in both countries. Widespread and useful palm species also face threats linked to overexploitation or habitat loss. Inclusive conservation measures should be designed to conserve, together with communities, this plant resource.

KEYWORDS

Aiphanes, Andes, anthromes, Chocó, ConR, dead palm standing syndrome, *Geonoma*, inhabited drylands

1 | INTRODUCTION

With over 2550 species, palms (Arecaceae/Palmae) are an ecologically dominant and quintessential plant resource across the tropics, particularly in the megadiverse tropical rain forest ecosystems (Dransfield et al., 2008; Pintaud et al., 2008). They provide a number of vital nature-based solutions and ecosystem resources to societies, especially in Global South countries (Balick & Beck, 1990; Cámara-Leret et al., 2017; Macía et al., 2011; Montúfar et al., 2022). For example, in northwestern South America over 60% (194 species) of palm species were reported to have at least one use and covering around 2300 uses in total (Macía et al., 2011). Nevertheless, palm communities face severe threats linked to anthropogenic impacts (deforestation, overexploitation and urban expansion) and climate change. Providing updated information on their diversity and conservation status is thus essential for a better management of this resource for human well-being across the tropics.

Together, Colombia and Ecuador are one of the most biodiverse regions on the planet (Barthlott et al., 2007). Ecuador has the highest concentration of palms (∼135–143 species and 32 genera) in South America relative to its size (Balslev et al., 2015; Borchsenius et al., 1998; Valencia & Montúfar, 2013), while Colombia is the second most diverse country for palms worldwide (∼270 species and 45 genera) behind Brazil (Bernal & Galeano, 2010, 2013). In both countries, palms have a wide variety of uses and are economically important, especially for rural populations (Borchsenius & Moraes, 2006; Brokamp et al., 2011; De la Torre et al., 2008, 2013; Gori et al., 2022; Macía et al., 2011; Montúfar et al., 2022; Negrão et al., 2022). Both countries have a long history of studying the taxonomy, ecology, ethnobotany, and conservation status and strategies of palms (Bernal, 1989; Bernal & Galeano, 2010; Borchsenius et al., 1998; Borchsenius & Skov, 1999; Galeano & Bernal, 2005; Valencia et al., 2000).

Both countries harbor significant portions of two of the 36 world biodiversity hotspots (Mittermeier et al., 2011; Zachos & Habel, 2011): Tumbes-Chocó-Magdalena and Tropical Andes (Figure 1a). The former, located on the Pacific side of the Andes extends from south Panama/north Colombia including the Magdalena Valley to northern Peru, forming a north–south gradient of humidity and precipitation, including one of the wettest regions on the planet (Gentry, 1986). This hotspot covers a number of different ecosystem types from tropical lowland and montane rain forests (Chocó) to the north and along the Andes, to seasonally dry forests (Tumbes) towards the south of Ecuador (Linares-Palomino et al., 2011; Rivas et al., 2021). The Tropical Andes hotspot, located along the Andes from Venezuela to northern Chile and Argentina, includes a wide variety of formations, gorges, valleys, and the altiplanos. It is one of the most biodiverse hotspots both in terms of species number and endemics (Mittermeier et al., 2011; Pérez-Escobar et al., 2022), and palms are no exception (Balslev et al., 2015; Pintaud et al., 2008).

Both hotspots, however, face severe challenges in terms of conservation. They have lost a significant portion of their original vegetation cover (Figures 1b, S1, and S2), especially forests (Armenteras et al., 2003; Dodson & Gentry, 1991; Mestanza-Ramón et al., 2022; Pérez-Escobar et al., 2022; Rivas et al., 2021; Sierra et al., 2021) and landscapes have been severely modified after a long legacy of anthropogenic disturbances (Duque et al., 2021). Indeed, these hotspots are located in regions linked to highly complex social and armed conflict histories (Oyola, 2015). In Ecuador, the Pacific coast and Andean region have undergone continuous intensive transformative changes linked to industrial plantations (i.e., palm oil, cacao, coffee, and banana), mining, urbanization, and road infrastructures (Mestanza-Ramón et al., 2022; Roy et al., 2018; Tamayo, 2019), mainly since the mid-19th and 20th centuries (Figure S2). Colombia, in addition to the problems cited above (Figure S1), has been prone to armed conflict for decades including in the Chocó region (Oyola, 2015), and together with the illegal expansion of coca plantations is linked to deforestation and biodiversity loss (Negret et al., 2019).

Here, we provide an updated study based on herbarium specimens of the diversity and preliminary conservation status of palms occurring within the limits of the Tumbes-Chocó-Magdalena and Tropical Andes hotspots in Colombia and Ecuador (Figure 1). In particular, we use the concept of anthromes (Ellis et al., 2021) to quantify how human activities in the region are linked to the distribution and conservation of palms. In contrast to biomes, which are based on the

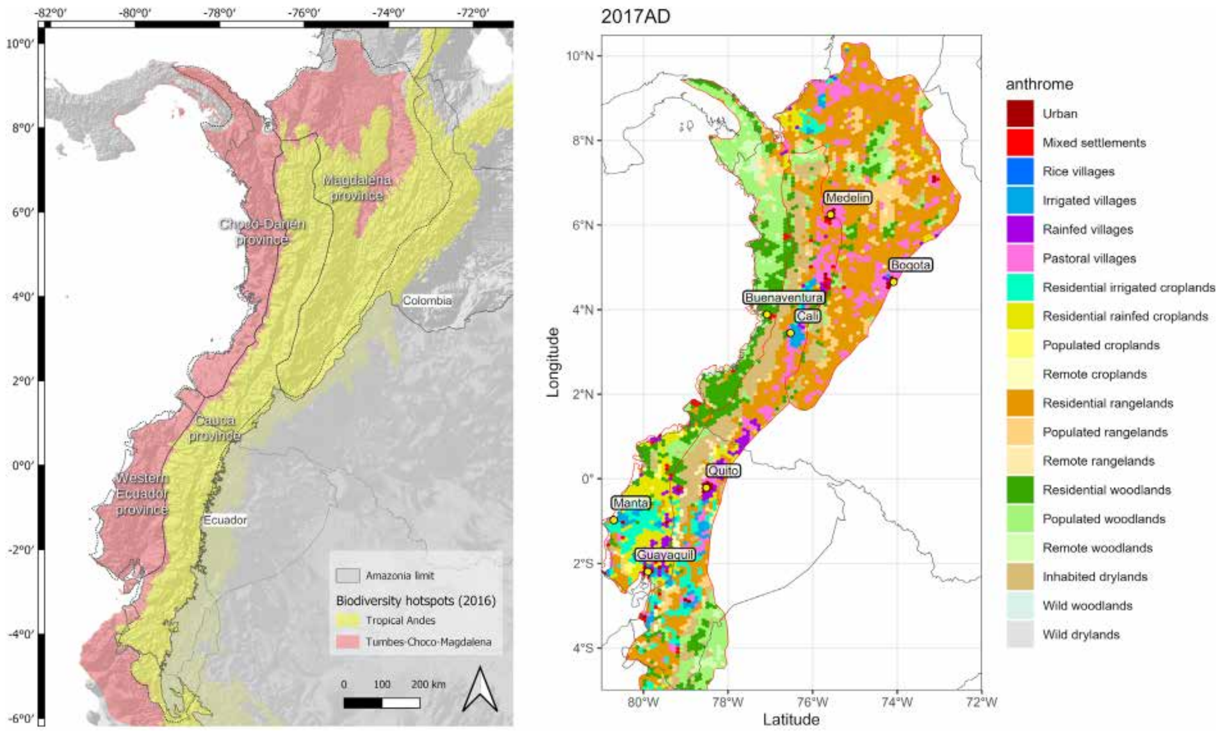

FIGURE 1 Maps of Colombia and Ecuador focusing on our study area. (a) Map showing the distribution of the Tumbes-Chocó-Magdalena (red) and Tropical Andes (yellow) biodiversity hotspots, and the four provinces based on Morrone (2014). Our study area only concerned limits within Colombia and Ecuador. (b) The 2017AD anthrome map of our study region, based on Ellis et al. (2021), and the locations of important towns. Cells are in the Discrete Global Grid (DDG) format, which represents the earth's surface as a grid of equal-area cells of 100 km^2. The Amazon basin shapefile was downloaded from https://databasin.org/ (Flores et al., 2010).

natural distribution of species, human-altered biomes or anthromes are defined based on human population densities, land uses at regional scales such as agriculture, cattle, or urbanization, and their interaction with the natural environment (Ellis et al., 2010; Ellis & Ramankutty, 2008).

2 | MATERIAL AND METHODS

2.1 | Study area

Our study area focused on two hotspots of biodiversity in Colombia and Ecuador (Figure 1a): Tumbes-Chocó-Magdalena and Tropical Andes (Mittermeier et al., 2011; Zachos & Habel, 2011). These regions cover the provinces of Western Ecuador, Chocó-Darién, Magdalena and Cauca following Morrone (2014). This region is characterized by its high rainfall, which has been recorded in the center of the department of Chocó (Colombia) in excess of 11,000 mm per year (Eslava, 1992). Our study area within the Tumbes-Chocó-Magdalena was equivalent to the previously recognized hotspot Chocó-Darién-Western Ecuador (Critical Ecosystem Partnership Fund [CEPF], 2001; Myers et al., 2000). In Colombia, this also includes the inter-Andean valleys of the Magdalena region. The Amazonian basin and the eastern flank of the Andes were excluded because palm use and management are different as well as conservation challenges between these regions.

2.2 | Database generation and curation

Distribution data was obtained by downloading georeferenced specimens for all species occurring in our study region via Global Biodiversity Information Facility (GBIF) (www.gbif.org) using the following options: "TaxonKey is Arecaceae"; "BasisOfRecord is Specimen"; "HasCoordinate is true", "HasGeospatialIssue is false", "OccurrenceStatus is Present". The GBIF Geometry POLYGON tool was used delimiting the study region in Colombia and Ecuador and in Panama. GBIF contains data from important palm collections for the region including these herbaria: AAU (Aarhus University, Denmark), MO (Missouri Botanical Garden, USA), COL (National University of Colombia), and NY (New Your Botanical Garden). This initial database was combined with the BioWeb database (www.bioweb.bio) which contains data from the QCA herbarium (Pontificia Universidad Católica del Ecuador). A database of palm specimens from Colombia was also included as compiled and georeferenced by the International Union for Conservation of Nature (IUCN) Colombian Plant Specialist Group and CES University (from herbaria COAH, COL, FMB, HUA y JAUM). We documented as precisely as possible rare/little collected species (likely threatened), while the distribution information for widespread species was less precise (i.e., not including all known specimens; likely not threatened).

Based on this initial database, if a species occurring in our study region was distributed beyond that region (widespread; i.e., *Iriartea deltoidea*, *Oenocarpus bataua*), data points were also included outside of our region. Precise documentation of widespread species occurring outside of our study region is not central to our study because they will be assessed as Least Concern. Naturalized or cultivated species were excluded.

We then updated all specimen identifications following recent taxonomic studies for each genus as follows: *Aiphanes* (Borchsenius & Bernal, 1996, and updated following Bernal et al., 2019); *Bactris* (Bernal et al., 2014; Henderson, 2000); *Ceroxylon* (Sanín & Galeano, 2011); *Desmoncus* (Henderson, 2011a); *Euterpe* and *Prestoea* (Henderson & Galeano, 1996); *Hyospathe* (Henderson, 2004); *Geonoma* (Henderson, 2011b); *Pholidostachys* (Henderson, 2012), *Reinhardtia* (Henderson, 2002); *Wettinia* (Bernal, 1995; Gracia et al., 2017). In some cases, we studied herbarium specimens stored at QCA or QCNE (National Herbarium of Ecuador) to confirm specimen identification.

Finally, we identified duplicate specimens (i.e., the same collector name and number, called a gathering). When two specimens of the same gathering had different identifications, we used the specimen with the identification of the known palm taxonomic expert of the genus (see above), the region, or the most recent determination (in that order). In the case of different geo-referencing coordinates between duplicate specimens, a detailed study was undertaken to select the more precise one using QGIS 3.20.3 and OpenStreetMap (https://www.openstreetmap.org/) for localities. Overall, using the publications cited above and palm floras for the region (Bernal & Galeano, 2010; Borchsenius et al., 1998; Henderson et al., 1995), we made sure that all species distributions were coherent with current knowledge.

This resulted in a "conservation dataset" with specimens from inside and outside our study region that was used for the conservation assessments (see below). Finally, we filtered the conservation dataset to only contain specimens from within our study region, resulting in the "diversity dataset" used to generate diversity maps.

2.3 | Distribution and diversity maps

We used the diversity dataset to generate diversity maps at the species and genus level across our study region. We used a grid cell size of 0.25 and 0.5°. Endemic species were defined as species with 100% of their occurrences in our database located within the defined region. All maps were generated in the R environment using the package *ggplot2* (Wickham, 2011). Scripts used are available at https://forge.ird.fr/diade/global_erc/palms_ec_col (Codes S1 and S2). ChatGPT v. 3.5 was used to edit and correct some of the R scripts.

2.4 | Preliminary IUCN conservation assessments

The IUCN Red List uses criteria to assess the conservation status of species and classify them according to their risk of extinction (IUCN, 2012). Criterion B, which is based on the geographical distribution of the species, is the most commonly used to evaluate plants (Schatz, 2002). Using the conservation dataset, we assigned a *preliminary* IUCN conservation status under Criterion B using the *ConR* package v. 1.3.0 (Dauby et al., 2017). *ConR* undertakes a batch analysis for all species and calculates the area of occupancy (AOO), the extent of occurrence (EOO), the number of subpopulations, and *estimates* the number of locations, as well as the percentage of occurrences in or outside of protected areas (PAs) (see above). For this analysis, locations were defined on the default value of 30 km^2 cell size (see Stévart et al., 2019). Although some of the assessments generated by *ConR* might not be a perfect match with a full IUCN assessment which is further based on expert evaluation of the species and ecosystems (Dauby et al., 2017), it provides nevertheless a good *preliminary* approximation (Nic Lughadha et al., 2019; Zizka et al., 2021). We use the term preliminary here to highlight that these assessments are not full assessments *following* IUCN, and should be considered as such.

Presence, species number, and specimens collected in and out of PAs within our study region were estimated using the Protected Planet shapefile (www.protectedplanet.net) in the *ConR* analysis. We undertook the *ConR* analyses with and without taking into account PAs. There are two main differences: (1) all occurrences of a species within a specific PA are considered as a single locality, and (2) if the occurrences of a species are 100% in a single PA then the species is suggested to be Least Concern because we cannot identify a potential threat in the future. This assumption is of course a best-case scenario.

2.5 | Anthromes

We used the recently published and updated anthromes dataset (Ellis et al., 2021) to estimate the different degrees of exposure of palms to human activities in our study region. This dataset provides a global map of human-altered biomes or landscapes such as croplands, rangelands, and urban areas. Anthromes are derived from the HYDE v. 3.2 (History Database of the Global Environment) dataset (Klein Goldewijk et al., 2017) which combines historical socio-economic data, land-use change models, and satellite imagery data from 10,000 BCE to the present (2017 in v. 3.2). Categorization is based on human population densities linked to forest cover and intensive land uses (crops, pastures, and cities) at a regional landscape scale ($\sim$100 km^2; Figure 1).

The anthromes database was downloaded into R using the *anthromes* package (https://github.com/nick-gauthier/anthromes) and were cropped to our study region (see above). To have a historical perspective of land-use change across the region we generated two time series showing the evolution of anthromes from 1900 AD to 2017 AD. A correlation analysis was performed to assess the relationship between the number of anthromes and the number of specimens per species. Pearson's correlation coefficient (r) was employed to quantify the strength and direction of the linear relationship between the two variables. The cor() function in base R was used to calculate the correlation coefficient. Statistical significance was assessed with a two-tailed hypothesis test. In addition, for each species assessed as threatened by ConR, we calculated the percentage of specimens occurring in each anthrome.

Finally, anthromes were classified into two major types, one related to land use intensity (very high impact to low impact) and one related to human population density (high density to low density). We generated treemaps, with rectangles proportional to specimen number, to visualize how many palm specimens (points) and species occur in each of the defined anthromes and types in the present day (2017 AD).

3 | RESULTS

3.1 | Genus and species diversity in the study region

The raw database contained 7891 unique herbarium specimens (Dataset S1, Figure S3). This value includes specimens outside our study area for non-endemic species (see Section 2). Of these, 412 specimens were not identified to species level and were discarded, resulting in 7479 specimens used to estimate the conservation status. Finally, the diversity dataset contained 4636 identified specimens (Figure S4) occurring in our study region (Figure 2a).

We document 144 native species (55 endemic), in 33 genera of palms occurring in our study region (Tables 1 and S1). The most diverse genus is *Aiphanes* with 24 accepted species, followed by *Geonoma* with 23, while 14 genera are represented by one species in our study region (Table 1). A total of 133 species (33 genera) occur in the study region in Colombia while 71 species (24 genera; Table S1) are registered for our study region in Ecuador (Table S1). Colombia harbors 43 endemic species, while Ecuador has nine (Table 2). Finally, we record 98 species (8 endemic) in 31 genera occurring in the Chocó region (Western Ecuador and Chocó-Darién provinces), 109 species (12 endemic) and 29 genera in the Cauca province, and 89 species (15 endemic) and 25 genera in the Magdalena province.

3.2 | Diversity patterns

Diversity patterns were the same between the 0.25° (Figure S5) and 0.5° cells (Figure 2), and we used the latter for the rest of the results and discussion. The highest diversity of palms both at genus and species level is located in the Chocó region and to a lesser extent the Magdalena Valley in Colombia (Figure 2b,c; Figure S5). The most diverse cells in terms of genera contained 20 genera (Figure 2b), located around the "Estación Ambiental Biológica de Tutunendó" and Buenaventura; and in northern Esmeraldas in Ecuador. Overall, regions with high generic diversity also contained high species diversity. A total of 13 grid cells of 0.5° documented 30 or more species of palms, with the maximum number of species reaching 53 in a grid cell located in the lowland rain forests of Chocó near the town of Buenaventura in Colombia (Figure 2c). The second most diverse grid cell was located in the Tropical Andes hotspot near the "Parque Nacional Las Orquídeas", in the Antioquia department of northern Colombia with 45 species. In Ecuador, the highest diversity was documented for two cells in northern Esmeraldas, near the border with Colombia having 34 and 38 species.

3.3 | Preliminary IUCN assessments and protected areas

Including or not PA in the *ConR* analyses leads to similar results (Table 2). The total number of threatened species increased from 47 with PAs to 50 without PAs. The main difference concerned two species that are only known from a single PA, resulting in *ConR* assigning them LC status when taking PA into account rather than CR without PA (Table 2; *Aiphanes cogollo* and *Ceroxylon sasaimae*). To remain conservative and follow previous assessments of these species as CR (Bernal et al., 2019; Sanín & Galeano, 2011), we will present and discuss the results of *ConR* without taking PA into consideration (but see Table S2 for all results). Another parameter not taken into account in this version of ConR is "highly fragmented." For example, *Aiphanes buenaventurae* is known from two localities, which places it in the Vulnerable (VU) category, however, this species is highly fragmented with an AOO of 4 km^2 and thus should be Critically Endangered (CR). In addition, one of those localities is located in the Urban anthrome, near the town of Buenaventura (Figure 3c).

The resulting IUCN parameters from *ConR* outputs indicated that just over a third of palm species (34.7%; 50/144) in our region are potentially threatened with extinction (Figure 3a,b, Table 2; Table S2). Of these, 12 species (8.3%) were classified as CR (Figure 3a,b, Table 2). In the Chocó and western Andes of Colombia, approximately 83% (36/43) of endemic palms are potentially threatened (Table 2). In Ecuador, five out of nine endemic species (62%) are threatened (Table 2). These potentially threatened species occurred in a range of different anthromes, especially those assessed as VU (Figure 3c). The genera *Aiphanes* and *Geonoma* contain the highest and second highest number of threatened species, respectively (Table 1). Spatially, several regions were shown to have high levels of potentially threatened species such as the Magdalena valley and along the Chocó region in both Colombia and Ecuador (Figure 2d).

A total of 115 species (~80%) and all 33 genera have at least one specimen documented in one of the PAs of Colombia or Ecuador but for 77 of these less than 10 specimens occur in a PA (Table S3). The VI category from the IUCN PAs classification scheme contained the highest number of species, followed by the II category (Table 3).

3.4 | Anthromes

Human activities have significantly impacted both countries over the course of the last century (Figures S1, S2, and S5). The Chocó of Colombia has remained relatively free of human activities compared with areas within our study region (Figure S1) harboring significant expanses of remote woodlands. The Chocó of Ecuador, in contrast, underwent rapid anthropization throughout the 20th century, as did the Andes and Magdalena valley in Colombia (Figures S1 and S2).

A total of 4636 specimens were collected within a defined anthrome (Figure S4). The 93 specimens not classified within an anthrome were located outside of the pixel (close to the sea or

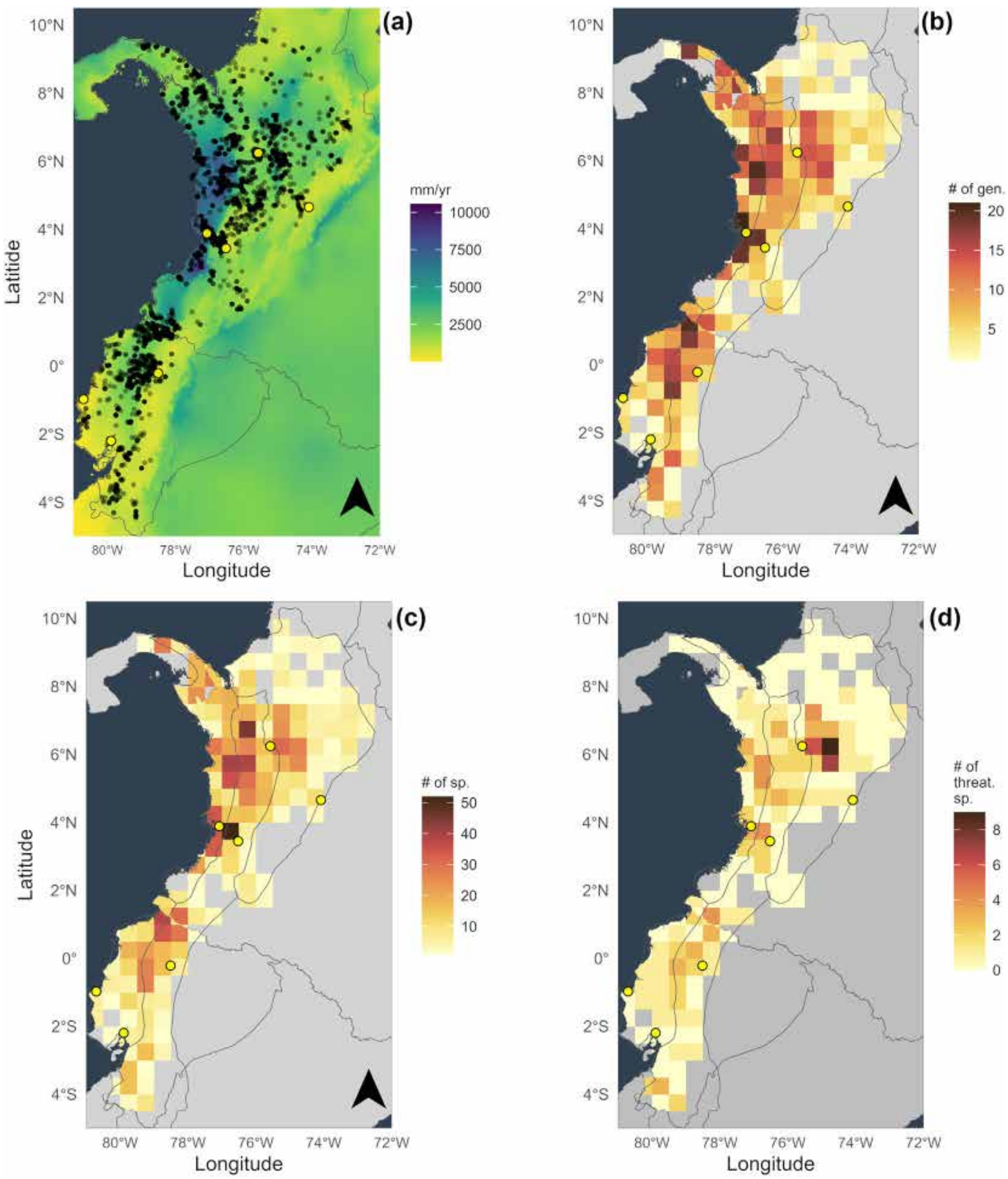

FIGURE 2 Distribution of diversity and potentially threatened species of palms in the Tumbes-Chocó-Magdalena and Tropical Andes hotspots of Colombia and Ecuador. (a) Distribution of specimens in our database (diversity dataset), overlaid on annual precipitation. (b) Generic diversity (total number of different genera). (c) Species diversity (total number of different species). (d) Number of potentially threatened species. Grid cells 0.5°; yellow dots represent major towns in the study region (see Figure 1).

border). We manually assigned missing anthromes only to the specimens of the species identified as threatened using *ConR* (seven specimens). The data revealed a strong positive correlation between the number of anthromes and the number of specimens per species (Pearson's $r = 0.7$, $p << 0.01$, Figure S5). In total, 60% of collections representing 135 species occurred within the "low human impact" land use type (Figure 4a), with 42% of specimens collected in either "Inhabited drylands" (23.10%; 1051 specimens, 95 species, see Figure S6) or "Residential woodlands" (19.20%; 873 specimens; 106 species). The former refers to regions defined as "Inhabited treeless and barren lands" (Ellis et al., 2010) but was later renamed "Inhabited drylands" (Ellis et al., 2021, see below for a discussion on this specific point). This anthrome represents woodlands (forests), with little grazing or crops (less than 20%), but can be used for other purposes and with low or no population density (Ellis et al., 2010). The second most important type of anthrome was "medium impact" representing 21% of all specimens and containing 114 unique species (Figure 4a).

In terms of the human density type (Figure 4b), 41% of all collections (1844) representing 131 species, were made in the Residential

TABLE 1 List of native palm genera and total number of species documented in the Tumbes-Chocó-Magdalena and Tropical Andes hotspots in Colombia and Ecuador. The number of threatened species is based on not taking protected areas into account during the *ConR* analyses. The last row includes genera with just one species occurring in our region.

Genus	Total number of species	Number threatened	Endemic to Colombia (potentially threatened)	Endemic to Ecuador (potentially threatened)
Aiphanes	25	15	14 (11)	4 (3)
Geonoma	23	9	7 (7)	2 (2)
Bactris	14	2	3 (2)	0 (0)
Wettinia	10	2	3 (2)	0 (0)
Chamaedorea	9	2	2 (2)	0 (0)
Ceroxylon	8	5	1 (1)	2 (2)
Attalea	6	3	3 (2)	0 (0)
Prestoea	5	0	0 (0)	0 (0)
Hyospathe	4	2	2 (2)	0 (0)
Pholidostachys	7	1	1 (1)	0 (0)
Astrocaryum	3	1	2 (1)	0 (0)
Phytelephas	3	1	0 (0)	1 (0)
Socratea	3	1	0 (0)	0 (0)
Calyptrogyne	2	1	1 (1)	0 (0)
Cryosophila	2	1	1 (1)	0 (0)
Desmoncus	2	0	0 (0)	0 (0)
Euterpe	2	0	0 (0)	0 (0)
Oenocarpus	2	0	0 (0)	0 (0)
Ammandra; *Asterogyne*; *Chelyocarpus*; *Dictyocaryum*; *Iriartea*; *Manicaria*; *Mauritiella*; *Parajubaea*; *Raphia*; *Sabal*; *Sabinaria*; *Syagrus*; *Synechanthus*; *Welfia*	1	*Sabinaria*: (1)	*Ammandra*: (1 [0]); *Mauritiella*: (1 [0]); *Sabinaria*: (1 [1])	0 (0)
Total	144			

category, linked to high human presence. The most remote and less human-impacted anthrome (remote woodlands) contains only a fraction of specimens (88) representing 33 species (Figure 4) and mainly occurs in the Colombian Chocó (Figure 1a) which has changed little over time (Figure S1).

4 | DISCUSSION

4.1 | Diversity of palms

Using a taxonomically verified database of 7479 identified palm herbarium specimens, we document the presence of 144 native species in 33 genera in the hotspots of Colombia and Ecuador (see Section 2, Figure 1). Given its size (~561,700 km^2), this region is thus quite diverse for palms (Balslev et al., 2015). With 133 (out of ~240) and 71 (out of 136) species, respectively, both hotspots contain about 55% of the species known for each country (Bernal & Galeano, 2010; Valencia & Montúfar, 2013). This high diversity is mainly due to the geodiversity and climatic variation across the region (Figure 1), being at the junction of three major bioregions in South America: the Chocó, the dry forest region of Tumbes (southern Ecuador), and the Andes Mountain range (Borchsenius & Skov, 1999). The Chocó biogeographic region is known for its high levels of floral diversity and endemism in general (Pérez-Escobar et al., 2019).

The 0.5° grid cells with the highest diversity in terms of both species and genera are located in the Chocó region (Figure 2b,c). These results, especially for the municipality of Buenaventura, are similar to those presented by Copete et al. (2019), where 42 palm species in 2.5 ha in Bahia Malaga were recorded. Copete et al. (2019) also demonstrated that palm diversity is correlated with precipitation in the Chocó. Indeed, precipitation is an important factor explaining palm richness in the Chocó (Copete et al., 2019; Gentry, 1986), the rainiest region in the Americas (~11,000 mm per year). In addition, both generic and specific diversity are high along the base of the Andes in northwestern Ecuador, in the Colombian Chocó, and in parts of the Magdalena Valley (Figure 2b,c). These regions have been documented as being very diverse in past studies (Dodson & Gentry, 1991; Gentry, 1986). Finally, the Parque Nacional Natural Las Orquídeas is another palm hotspot to highlight because it is influenced by both Chocó and Andean floras on the two slopes of the Cordillera Occidental.

The two most diverse genera are *Aiphanes* (25 species out of 36) and *Geonoma* (23 species out of 68). *Aiphanes* is an Andean-centered genus, with many species occurring in Colombia (Borchsenius & Bernal, 1996; Henderson, 2011b; Sanín et al., 2022) in particular since

TABLE 2 List of the 50 potentially threatened palm species occurring in the hotspots of Tumbes-Chocó-Magdalena and Tropical Andes in Colombia and Ecuador. Preliminary conservation assessments are based on Criterion B of the International Union for Conservation of Nature (IUCN). These are the direct outputs of *ConR*: extension of occurrence (EOO, B1), area of occupancy (AOO, B2), (a) number of locations (IUCN, 2012) when taking into account Protected Areas (PAs) or not in the *ConR* analysis. In bold are species that changed status depending on whether or not we consider PAs in the *ConR* analysis.

Species	Distribution	EOO	AOO	# unique occurrences	# locations (PA/no PA)	# locations in PA	Ratio occurence within PA (%)	*ConR* inferred preliminary category with PA	*ConR* inferred preliminary category without PA
Aiphanes acaulis	Colombia	1135	24	6	4/	0	0	EN B1a + B2a	EN B1a + B2a
Aiphanes argos	Colombia	12	12	3	2/2	0	0	EN B1a + B2a	EN B1a + B2a
Aiphanes bicornis	Ecuador	3761	44	12	9/9	0	0	VU B1a + B2a	VU B1a + B2a
Aiphanes bio	Colombia	8	8	3	1/1	0	0	CR B1a	CR B1a
Aiphanes buenaventurae	Colombia		4	2	2/2	0	0	EN B2a	EN B2a
Aiphanes cogollo	**Colombia**		**4**	**1**	**1/1**	**1**	**100**	**LC or NT B2a**	**CR B2a**
Aiphanes decipiens	Colombia	61	16	4	3/3	0	0	EN B1a + B2a	EN B1a + B2a
Aiphanes duquei	**Colombia**	**309**	**20**	**6**	**6/5**	**4**	**66.7**	**VU B1a + B2a**	**EN B1a + B2a**
Aiphanes eggersii	Ecuador	17,465	40	11	10/10	0	0	VU B1a + B2a	VU B1a + B2a
Aiphanes gelatinosa	Colombia	35	16	5	2/2	0	0	EN B1a + B2a	EN B1a + B2a
Aiphanes gloria	Colombia	124	20	5	3/3	1	20	EN B1a + B2a	EN B1a + B2a
Aiphanes grandis	Ecuador	1002	20	7	4/4	0	0	EN B1a + B2a	EN B1a + B2a
Aiphanes multiplex	Colombia/Ecuador	**9147**	**24**	**6**	**6/5**	**3**	**50**	**VU B1a + B2a**	**EN B2a**
Aiphanes parvifolia	Colombia	36	12	4	3/2	2	75	EN B1a + B2a	EN B1a + B2a
Aiphanes tatama	Colombia		4	1	1/1	0	0	CR B2a	CR B2a
Astrocaryum pax	Colombia		4	1	1/1	0	0	CR B2a	CR B2a
Attalea amygdalina	Colombia	45,261	28	7	6/6	0	0	VU B2a	VU B2a
Attalea cohune	MesoAmerica/Colombia	383,545	32	8	8/8	1	12.5	VU B2a	VU B2a
Attalea cuatrecasasiana	Colombia	13,364	28	7	6/6	0	0	VU B1a + B2a	VU B1a + B2a
Bactris chocoensis	Colombia	14	8	3	2/2	0	0	EN B1a + B2a	EN B1a + B2a
Bactris rostrata	Colombia	5970	12	3	3/3	0	0	EN B2a	EN B2a
Calyptrogyne baudensis	Colombia	285	20	6	3/4	1	33.3	EN B1a + B2a	EN B1a + B2a
Ceroxylon alpinum	Colombia/Venezuela	79,688	36	11	8/8	2	27.3	VU B2a	VU B2a
Ceroxylon echinulatum	Ecuador	11,638	44	12	8/8	0	0	VU B1a + B2a	VU B1a + B2a
Ceroxylon parvum	Ecuador		4	1	1/1	0	0	CR B2a	CR B2a
Ceroxylon sasaimae	**Colombia**		**4**	**1**	**1/1**	**1**	**100**	**LC or NT B2a**	**CR B2a**
Ceroxylon ventricosum	Colombia/Ecuador	138,594	36	10	8/8	0	0	VU B2a	VU B2a

TABLE 2 (Continued)

Species	Distribution	EOO	AOO	# unique occurrences	# locations (PA/no PA)	# locations in PA	Ratio occurence within PA (%)	*ConR* inferred preliminary category with PA	*ConR* inferred preliminary category without PA
Chamaedorea christinae	Colombia		4	2	1/1	0	0	CR B2a	CR B2a
Chamaedorea ricardoi	Colombia	975	16	4	4/4	0	0	EN B1a + B2a	EN B1a + B2a
Cryosophila macrocarpa	Colombia	8	8	3	1/1	0	0	CR B1a	CR B1a
Geonoma bernalii	Colombia		8	2	2/2	0	0	EN B2a	EN B2a
Geonoma chlamydostachys	Colombia	8909	32	9	8/8	1	11.1	VU B1a + B2a	VU B1a + B2a
Geonoma dindoensis	Colombia		4	1	1/1	0	0	CR B2a	CR B2a
Geonoma divisa	Colombia	6696	32	9	7/7	1	22.2	VU B1a + B2a	VU B1a + B2a
Geonoma frontinensis	Colombia	49,550	40	10	9/9	1	10	VU B2a	VU B2a
Geonoma galeanoae	Colombia	15	12	3	3/3	1	33.3	EN B1a + B2a	EN B1a + B2a
Geonoma gentryi	Colombia		4	1	1/1	0	0	CR B2a	CR B2a
Geonoma tenuissima	Ecuador	13,587	44	13	7/7	0	0	VU B1a + B2a	VU B1a + B2a
Geonoma venosa	Ecuador	12	12	4	1/1	0	0	CR B1a + B2a	CR B1a + B2a
Hyospathe frontinensis	Colombia	43,220	60	19	7/8	4	84.2	VU B2a	VU B2a
Hyospathe wendlandiana	Colombia	183	12	3	2/2	1	33.3	EN B1a + B2a	EN B1a + B2a
Parajubaea cocoides	Andes	55,294	36	10	9/9	0	0	VU B2a	VU B2a
Pholidostachys sanluisensis	Colombia	61	12	3	3/2	1	33.3	EN B1a + B2a	EN B1a + B2a
Phytelephas tumacana	Colombia/Ecuador	876	24	7	5/5	0	0	EN B1a + B2a	EN B1a + B2a
Raphia taedigera	Colombia/Panama/Brazil	6781	16	4	4/4	1	25	EN B2a	EN B2a
Sabinaria magnifica	Colombia	8	8	3	1/1	1	100	CR B1a	CR B1a
Socratea hecatonandra	Colombia/Ecuador	51,900	36	9	8/8	1	11.1	VU B2a	VU B2a
Wettinia castanea	Colombia	44,824	36	10	7/7	1	10	VU B2a	VU B2a
Wettinia disticha	Colombia	7159	28	7	7/6	5	71.4	VU B1a + B2a	VU B1a + B2a
Wettinia verruculosa	Colombia/Ecuador	510	28	7	4/4	2	28.6	EN B1a + B2a	EN B1a + B2a

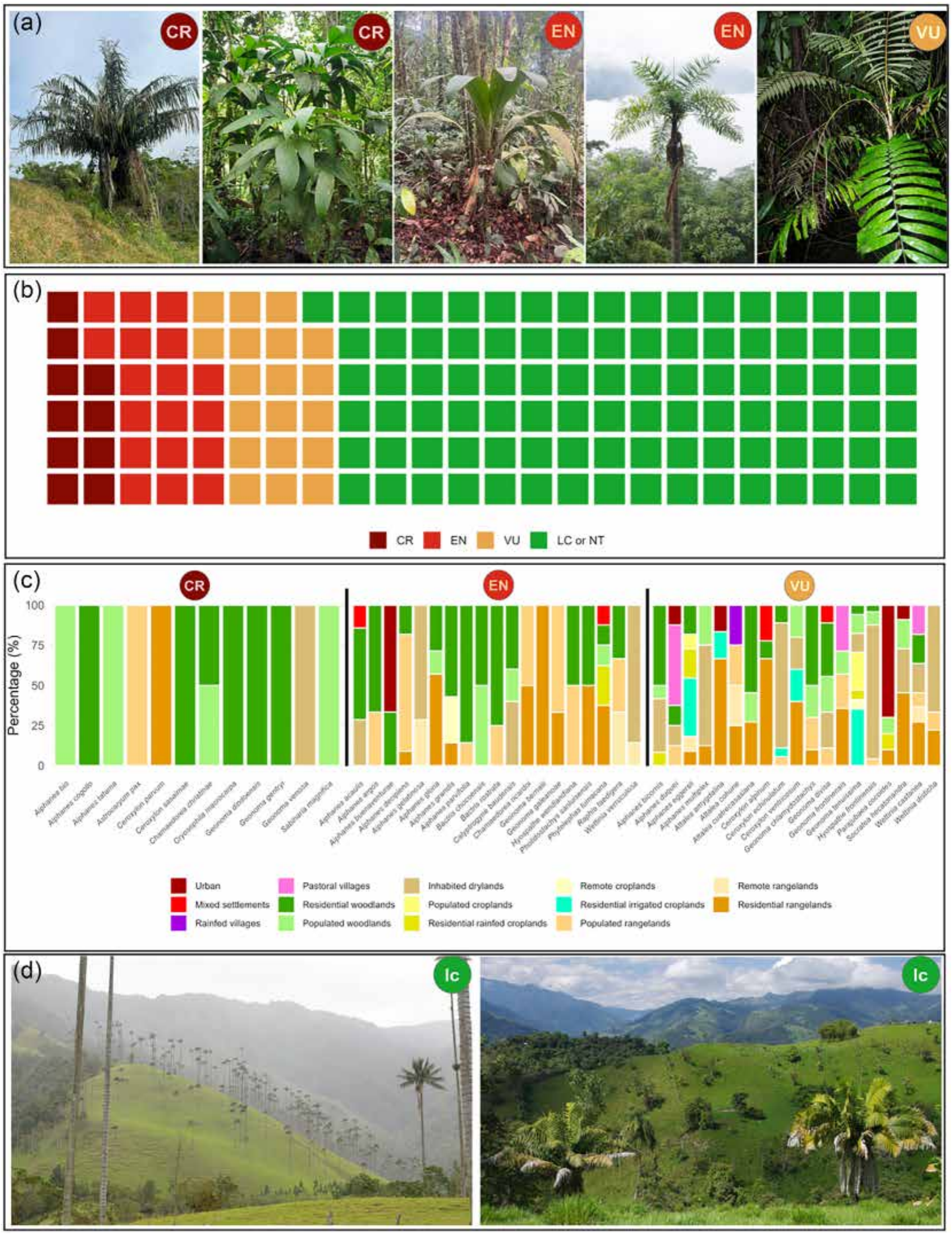

FIGURE 3 Preliminary conservation assessment and anthrome proportions of 144 threatened palm species in the Tumbes-Chocó-Magdalena and Tropical Andes hotspots of Colombia and Ecuador. (a) Photos of a few preliminary assessed threatend palm species: Critically Endangered (CR): *Astrocaryum pax* (endemic to Colombia, photo J.C. Copete) and *Geonoma venosa* (endemic to Ecuador, photo T.L.P. Couvreur); Endangered (EN): *Bactris chocoensis* (endemic to Colombia; photo J.C. Copete) and *Aiphanes grandis* (endemic to Ecuador, photo T.L.P. Couvreur); Vulnerable (VU): *Aiphanes bicornis* (endemic to Ecuador, photo T.L.P. Couvreur). (b) Waffle chart showing the direct output of the ConR R package and using the conservation dataset and not taking into account protected areas (PAs). (c) Proportion of specimens per threatened species occurring in the different anthromes. (d) Example of "dead palm standing" populations in our study region. Left: scattered individuals of *Ceroxylon quindiuense (the tallest palm in the world)*, here assessed as Least Concern (lc) (Colombia, photo T.L.P. Couvreur). Right: *Phytelephas aequatorialis* persisting in a deforested region of western Ecuador, here assessed as Least Concern (lc) (photo T.L.P. Couvreur).

the revision of the *Aiphanes parviflora* complex (Bernal et al., 2019). *Aiphanes* is suggested to have diversified by tracking high precipitation up and down the Andean altitudinal range possibly explaining the high number of range-restricted, and thus potentially threatened, species (Sanín et al., 2022). *Geonoma* is more diverse in the lowland rain forests of the Chocó (Henderson, 2011b). Ecological divergence and local adaptation are suggested to drive its diversification, at least in the Amazon (Bacon et al., 2021).

In contrast, we also highlight regions where palms appear to be poorly documented (Figure 2a,b). These are mainly found in Colombia, such as the northern part of Nariño, north of Huila, and south of Tolima. These regions should be targeted for increased sampling as they could harbor potentially threatened species. In Ecuador, most of our study region at 0.5° cells are documented by at least some records (Figure 2a,b). The cells with no or few records are located in the southern part of Guayas, around the city of Guayaquil. This, however, is linked to the drier deciduous forest ecosystems that dominate there (Valencia & Montúfar, 2013; see Figure 2a), with a dry season lasting 6 months where few palms occur (e.g., *Aiphanes eggersii*; *Attalea colenda*; *Bactris gasipaes* var. *chichagui*). In addition, species that were once abundant, are now rare in the region, such as the ivory palm *Phytelephas aequatorialis* (Valencia & Montúfar, 2013) and *Astrocaryum standleyanum*.

TABLE 3 Number of species with at least one occurrence in protected areas (PAs), following the IUCN classification, occurring in the hotspots of Tumbes-Chocó-Magdalena and Tropical Andes of Colombia and Ecuador. Category II – national park; Category IV – habitat or species management area; Category V – protected landscape; Category VI – protected area with sustainable use of natural resources.

IUCN PA category	Total species
II	82
IV	4
V	9
VI	97
No information	8
Not applicable	1
Not reported	40

Abbreviation: IUCN, International Union for Conservation of Nature.

4.2 | Conservation of palms

By applying a *preliminary* conservation assessment approach using IUCN Criterion B (Dauby et al., 2017), we show that around a third of all palm species documented in the two hotspots of Ecuador and Colombia are likely globally threatened with extinction (34.7%; 50/144, PAs not taken into account; Figure 3; Table S2). This value is

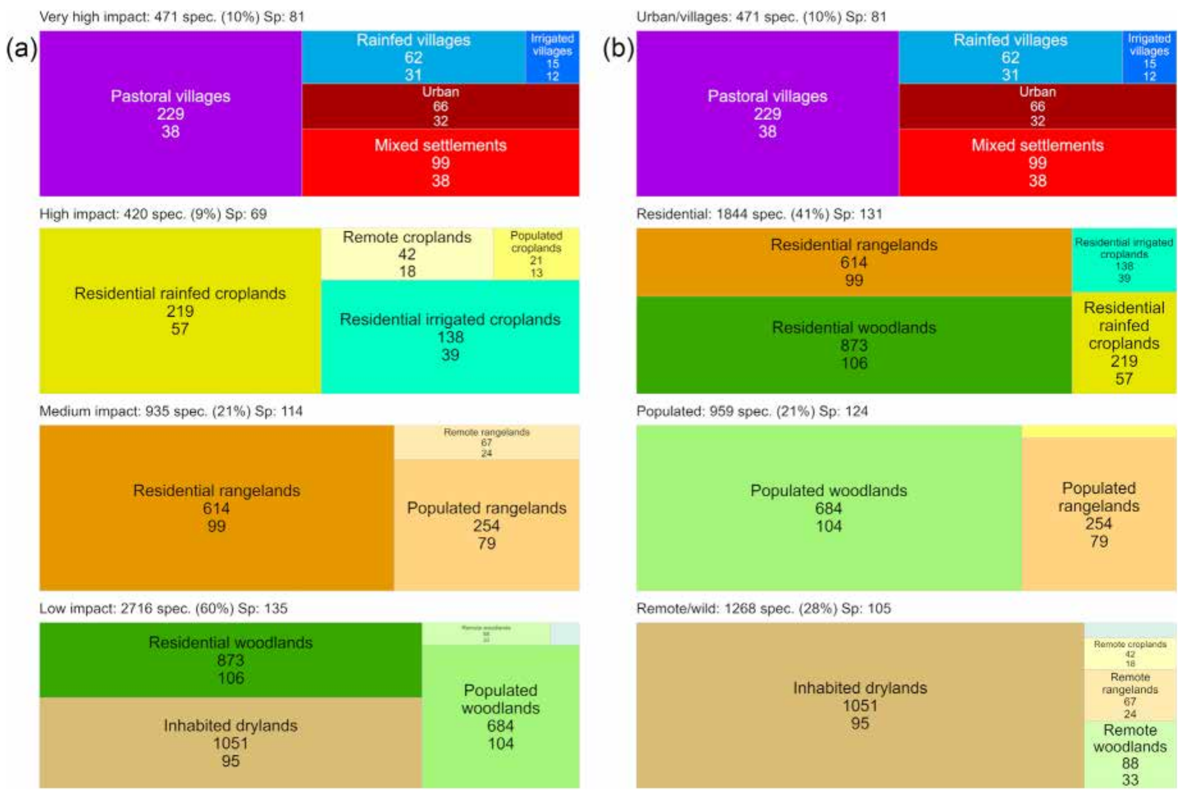

FIGURE 4 Tree map of specimens and palm species occurring in anthromes in the Tumbes-Chocó-Magdalena and Tropical Andes hotspots of Colombia and Ecuador. (a) Categorization based on human impact type, linked to land use (very high impact: towns and urban areas; high impact: croplands; medium impact: rangelands [pastures]; low impact: woodlands); (b) categorization based on human density type: urban or village: 100 > 2500 persons/km^2; residential: 10 > 100 persons/km^2; populated: 1 > 10 persons/km^2; remote and wild: 0 > 1 person/km^2. Colors in the treemaps are related to the colors in Figure 1b. Each box contains the names of the anthrome, the total number of specimens collected in that anthrome, and the total number of species documented in that anthrome. The values for each category represent the total number of specimens collected in that category and its percentage compared with the total; and the total number of species collected in that category.

higher than the 23% of threatened plant species inferred for the Neotropics as a whole based on the Sampled Red List Index approach (Brummitt et al., 2015) but lower than the 56% of threatened species inferred worldwide based on machine learning (Bellot et al., 2022). When focusing on endemic species, the situation is critical in both Colombia and Ecuador. The 83% (36/43) of endemic palms are potentially threatened in the Chocó and Andes of Colombia (Table 2) which is much higher than the 45% of all Colombian endemic tree species assessed as threatened (Lopez-Gallego & Morales-Morales, 2023). This level of threat is equivalent to those reported for Madagascar where 86% of the mostly endemic species were assessed as threatened (Rakotoarinivo et al., 2014, 2020) and close to the 78% of endemic plants assessed as threatened in Ecuador in general (León-Yánez et al., 2011). Several endemic and range-restricted species of *Aiphanes* in Colombia (Table 1), like *Aiphanes acaulis* and *Aiphanes argos*, grow exclusively along riverbeds and could be severely impacted by river damning and by mining (Borchsenius & Bernal, 1996; Sanín et al., 2022), both important in the Andes and Chocó regions of Colombia. Although these activities in some cases do not affect large extensions of forest, they pose a specific threat to riparian species. Finally, there are several range-restricted species of *Aiphanes* and *Geonoma* (*Aiphanes bio*, *Aiphanes gloria*, *Geonoma clamydostachys*, and *Geonoma galeanoae*) that grow in the lowlands and foothills of the Magdalena Valley in Colombia. These areas contain fewer PAs and have greater deforestation rates than in the Colombian Chocó (Sanchez-Cuervo & Aide, 2013), and thus higher number of potentially threatened species (Figure 2d).

Although we only register nine endemic species in western Ecuador, five (62%) are threatened. Of these, *Geonoma venosa* (Figure 3) which is endemic to the Andean Chocó region of Imbabura in Ecuador (Henderson, 2011b) a known deforestation hotspot (Kleemann et al., 2022) linked to mining activities (Mestanza-Ramón et al., 2022). This species is preliminarily assessed as CR by *ConR* (Table 2, Figure 3c) because a single population (i.e. location) is known to date. Based on fieldwork in this reserve in 2022 (Movie S1), we found adult and juvenile individuals in good condition growing in the well-protected and private Los Cedros Biological Reserve, well known for its high and unique biodiversity (Roy et al., 2018). This reserve recently won a court ruling revoking environmental permits granted to mining concessions in the reserve (Prieto Munoz, 2021). Nevertheless, the reserve occurs in an area with high deforestation threats (Kleemann et al., 2022) and thus threats to this population remain high.

A recent study applied machine learning linked to IUCN criteria and found that around 1000 palm species (out of 1889 species included in the study) were estimated to be threatened with extinction worldwide (Bellot et al., 2022). Interestingly, this study did not highlight Ecuador or Colombia as research or conservation priorities based on a number of criteria including usefulness and replaceability (potential alternatives for a useful species). Here, we document 14 palm species potentially threatened that are also reported as useful with up to six different use categories for a single species (Table S2). Three of these species belong to the genus *Ceroxylon*, the wax palm, an Andean-centered genus with multiple uses (Sanín & Galeano, 2011). Three out of the four threatened *Ceroxylon* species occur in highly human-impacted anthromes (Figure 3c). They should be the focus of urgent sustainable conservation actions (Duarte & Montúfar, 2012; Montúfar et al., 2011), especially because most of these species are now fragmented and potentially represent distinct evolutionary units (i.e., *Ceroxylon quindiuense*, Chacón-Vargas et al., 2020).

Our dataset suggests that around 80% of palm species in the study region have at least one specimen collected from a PA although 77 species have fewer than 10 collections in these PAs. PAs were defined here following IUCN, based on the level of human impact (Dudley et al., 2010) and are thus not equal in their protection level. We show that 82 species (∼62%, none endemic) occur in Category II PAs, which corresponds to areas with little human presence, while 94 (∼67%) species are reported to occur in a Category VI PA (Table 3), defined as areas with sustainable management of natural resources. Of these, two species are only known from this category: *Aiphanes cogollo* in the “Natural Reserve Cuchilla del Tigre, El Calón y La Osa” and *Ceroxylon sasaimae*. However, in general, this latter category (VI) received substantial criticism, questioning if it could be qualified as a PA at all (Dudley et al., 2010; Locke & Dearden, 2005). A recent study underlined that the network of Colombian National Parks (covering 11% of the territory) is effective against deforestation, even in regions with high deforestation pressure (Negret et al., 2019). However, we stress that local floras within PAs remain incomplete or undersampled, potentially biasing the results presented here, and should be updated as more regions are botanically explored. In addition, collective lands that do not figure in the network of PAs are also effective for biodiversity conservation in general (Fa et al., 2020) and in our study region in particular (Negret et al., 2019). Collective lands can be managed by indigenous communities (i.e., Awa Ethnic Reserve in northern Ecuador, Agua Blanca), local governments (“Distritos de Manejo Integral” in Colombia Acosta, 2013; “areas de conservación municipales”; i.e., Mashpi-Guaycuyacu in Ecuador), or private land owners, (i.e., Los Cedros Biological Reserve as mentioned above, Movie S1). These sanctuaries must also be taken into account, but there are no databases in place that document them in our region. Finally, PAs as currently delimited, might not be the best representation of conservation efforts when we factor in climate change impacts (Heywood, 2019). For example, when estimating evolutionary diversity across neotropical palms via the phylogenetic diversity metric, Velazco et al. (2021) showed that the current network of PA in South America was a poor protector of this diversity by the end of the century.

Based on our spatial analysis of palms and anthromes (Ellis et al., 2010), we show that most palm species and collections in our study region occur in areas with low land use intensity but with relatively high human presence (Figure 4). Interestingly, most PAs in the region are also associated with high human presence (see Figure 1a of Jones et al., 2018). Although the relationship of population density on biodiversity is complex, areas of high population concentrations are generally considered as negative for biodiversity conservation (Jones et al., 2018; Williams et al., 2020). In addition, several threatened species occur in anthromes linked to human-impacted lands such as *Aiphanes buenaventurae*, *Aiphanes gloria*, *Ceroxylon parvum*, *Ceroxylon alpinum*, and *Geonoma bernalii* (Figure 3c).

One counterintuitive result is the important proportion of palm specimens in the "Inhabited dryland" anthrome (Figure 4; Figure S7; Table S2). This anthrome (#54) was initially called "Inhabited treeless and barren lands" without the "dry" connotation (Ellis et al., 2010). It is defined as having low human density (>100), with less than 20% crops and no woodlands (Ellis et al., 2010). Based on our knowledge of the study area, this anthrome occurs in inhabited paramo regions (thus not dry). It also covers the transition zone between paramo and lowland forests along both sides of the flanks of the Andes (see Figure S7). These are regions that harbor montane Andean forests (between 1000 and 2000 m) that are smaller in tree stature than lowland rain forests (Grubb et al., 1963; Richards, 1996) and are thus possibly not detected as woodlands. It should also be noted that this anthrome appears to overlap with some of the deforestation hotspots known in Ecuador (Kleemann et al., 2022). Finally, palm species recorded in this anthrome (Table S4) are indeed mainly Andean forest species (Valencia & Montúfar, 2013) occurring above 1000 m (e.g., *Aiphanes chiribogensis*, *Ceroxylon echinulatum*, *Ceroxylon ventricosum*, *Geonoma undata*, *Wettinia oxycarpa*, and *Wettinia verruculosa*) or species with wide ecological distributions occurring in low and high elevation forests of the region (e.g., *Chamaedorea linearis*, *Chamaedorea pinnatifrons*, *Bactris setulosa*, and *Wettinia kalbreyeri*). One striking example is the CR *Geonoma venosa* palm which occurs entirely in this anthrome (Figure 3c, Figure S5A, Table S4, see above) even though it is an understory forest species occurring between 1200 and 1500 m (Henderson, 2011b). In conclusion, the name of this anthrome (#54) seems inappropriate in our study region underlying a limit to the global approach, especially when vegetation changes over small distances like the slopes of the Andes. This anthrome should probably be renamed (delete the reference to "dry") or refined to separate truly inhabited treeless dry/arid regions from inhabited treeless but humid regions near the equator (like paramo) or forests with lower statures in transition zones. Nevertheless, we note that for the purpose of our study, the conclusions are not changed as in terms of human impact, anthrome #54 refers to low land use and low human density (Figure 4).

Palms are particularly impacted by human land use changes. In many cases, when clearing forests for crops or rangelands, palms are left standing (Bernal & Sanín, 2013; Montúfar et al., 2011). This leads to a community with a "dead palm standing" syndrome (Figure 3d), where adults continue to grown but where basic ecological processes of population regeneration are stopped (seedlings destroyed or not surviving). This syndrome is exuberated for widespread useful and endemic species for Colombia or Ecuador such as *Ceroxylon quindiuense* (Figure 3d), *Attalea colenda*, or *Phytelephas aequatorialis* (Figure 3d). Thus, although these appear abundant, their populations are in fact doomed and will locally disappear (some estimates suggest under 50 years for *C. quindiuense*; Bernal & Sanín, 2013). This highlights a limitation when using the methodology applied in our study based on Criterion B (geographic distribution) as implemented in *ConR* v. 1.3 to evaluate conservation status. Thus, because palms in the Chocó and the western Andean region occur in highly human-impacted regions (Figures 4 and 1b), we predict that their conservation status is much more critical than our results imply. For example, *C. quindiuense* was evaluated as VU in 1998 (Bernal, 1998) and then as Endangered at the Colombian level (Calderón et al., 2005) and for which a new assessment is now needed. Species such as *Phytelephas aequatorialis*, subpopulations of *Euterpe oleracea*, *Manicaria saccifera*, and *Prestoea acuminata* cannot be considered unthreatened under Criterion B only, taking into account that management systems and market priorities unsustainably exploit these populations. National evaluations should be done to leverage these particular dynamics on these useful palm species. Overall, palms are being affected by habitat loss and degradation across the study area. Importantly, several useful species are also suffering from selective extraction and practices such as river damning and river mining that do not necessarily directly tie to denser human populations or large expansions of forest clearing. Finally, some widespread and morphologically complex palm species might represent distinct undescribed biological species (e.g., Bernal et al., 2019). For example, using genomic data, the morphologically diverse and widespread *Geonoma undata* (LC in our analysis) was suggested to be a case of hyper-cryptic plant radiation possibly representing 12 genetically distinct species (Olivares et al., 2024). In the future, this hidden diversity will have to be described and reevaluated.

5 | CONCLUSIONS

Our results suggest that a third of palm species are threatened with extinction across our study region in Colombia and Ecuador, but these proportions are much higher when we consider only the endemic species. There are limitations to our study, as these assessments were undertaken in *ConR*, and only based on Criterion B. *ConR* provides a rapid and preliminary regional assessment of the threat (Dauby et al., 2017) and does not necessarily include the human and economic forces that affect the conservation of many useful palms in this region which are affected by harvesting and trade. In this sense, our results provide only a first approach to understanding the conservation and threats to this important plant family in Colombia and Ecuador. Nevertheless, such preliminary analyses are useful to tackle assessments at large scales in a quick and efficient manner (i.e., Stévart et al., 2019). Full assessments including threat analysis are in the process of being submitted to the IUCN, which will be central for improved sustainable management of palms.

We show that the use of the anthromes framework is useful to gather a more nuanced view of biodiversity distribution and conservation (Erkens et al., 2023), as very few natural human-free areas remain. By exploring the distribution of palm specimens and diversity within anthromes, we show that this diversity is under high human pressure, except maybe in the northern part of the Colombian Chocó. Thus, appropriate conservation measures must be put in place, but these must take into account the communities and societies that live in these regions in addition to how we can sustainably exploit palm resources (Acosta, 2013). Finally, the use of anthromes has yet to be formally integrated into IUCN assessments and should be seen as complementary information for these evaluations.

AUTHOR CONTRIBUTIONS

Thomas L.P. Couvreur and Rommel Montufar planned, designed, and got funding for the research. Nayeli Jijon, Thomas L.P. Couvreur, Álvaro J. Pérez, Rommel Montufar, Juan Carlos Copete, Maria José Sanín, Alix Lozinguez, and Paula A. Morales-Morales conducted fieldwork. Paula A. Morales-Morales, Emily Beech, Juan Carlos Copete, Maria José Sanín, Alix Lozinguez, and Álvaro J. Pérez contributed data. Nayeli Jijon and Thomas L.P. Couvreur analyzed data. Nayeli Jijon, Thomas L.P. Couvreur, and Rommel Montufar led the writing. All authors commented and read the final versions of the MS.

ACKNOWLEDGMENTS

The authors wish to thank MSc. Susana León of the herbarium QCA of the Pontificia Universidad Católica del Ecuador and Dr. Marcia Peñafiel of the Herbario Nacional del Ecuador (QCNE), Museo Ecuatoriano de Ciencias Naturales for allowing us to access palm specimens. The authors also thank Cristina Lopez-Gallego for allowing us to have access to the Colombian palm dataset generated within the IUCN SSC Colombian Plant Specialist Group.

We thank Josef DeCoux director of the Los Cedros Biological Reserve (Ecuador) for access to the reserve to document *Geonoma venosa*. We also thank Jordan Karubian of the FCAT reserve (Mache-Chindul Ecological Reserve) for lodging and access to the forest. Finally, we thank two anonymous reviewers and the editor for improving the quality of this article.

Results presented here were in part funded by the IUCN SSC Internal Grant (re: wild grant number SMA-G00-00214; *Red Listing the palm species of western Ecuador*) to RM and TLPC. TLPC is supported by funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement no. 865787). This research was also undertaken within the Laboratoire Mixte International (LMI) BIO_INCA (http://bioinca.org/).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that allows to reproduce the results in this study are available in the Supporting Information of this article. The full datasets that support the findings of this study are available on request from the corresponding author. The distribution dataset is not publicly available due to privacy or ethical restrictions, and additional requests will be needed from the different institutions that provided this data in Colombia.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Couvreur, T. L. P., Jijon, N., Montúfar, R., Morales-Morales, P. A., Sanín, M. J., Copete, J. C., Lozinguez, A., Pérez, Á. J., & Beech, E. (2024). Diversity and conservation status of palms (Arecaceae) in two hotspots of biodiversity in Colombia and Ecuador. *Plants, People, Planet*, 1–17. https://doi.org/10.1002/ppp3.10506