

# MULTICRITERIA ASSESSMENT OF VEGETATION THREATS IN THE COLOMBIAN ORINOQUIA

VLADIMIR MINORTA-CELY<sup>1</sup>, LARRY NIÑO<sup>2</sup>, ORLANDO RANGEL<sup>2</sup>, DIEGO GIRALDO-CAÑAS<sup>2</sup>,  
GERARDO AYMARD<sup>3</sup> AND DANIEL SÁNCHEZ-MATA<sup>4</sup>

**Abstract.** In the Colombian Orinoquia, the main threats to the conservation of natural vegetation are selective logging in forests and land-use changes in grasslands. To assess these threats, an ordinal classification was conducted based on the degree of conservation urgency of vegetation types (phytosociological alliances). A multicriteria model was developed using the Analytic Hierarchy Process (AHP), integrating data from the IUCN Red List of Threatened Species, field inventories of local plant uses, species dominance, and assessments of habitat quality. A total of 281 vegetation plots in grasslands and 178 in forests were analyzed. In the grasslands, one phytosociological alliance was classified as critically threatened, whereas in forests, three alliances were identified as highly threatened. While IUCN categories facilitate comparative assessments of species' conservation status, they do not explicitly reflect the specific threats affecting vegetation types. We propose that multicriteria models for threat assessment provide a more comprehensive understanding of the pressures and conservation status of each vegetation type, thereby offering a more robust framework for guiding conservation efforts. Threat assessments of vegetation types are essential inputs for territorial zoning processes, land-use planning, and the management of protected areas.

**Keywords:** Neotropical savannas, Colombian Orinoquian region, vegetation types of Colombia, threatened flora and vegetation of Colombia, Analytic Hierarchy Process (AHP)

**Resumen.** En la Orinoquia colombiana, las principales amenazas para la conservación de las condiciones naturales de la vegetación, son la explotación maderera de los bosques y los cambios de uso del suelo en los pastizales. Con el fin de evaluarlas, se realizó una clasificación ordinal basada en el grado de urgencia de conservación de la vegetación (alianzas fitosociológicas). Para ello, se desarrolló un modelo multicriterio utilizando el Proceso Analítico Jerárquico (AHP, por sus siglas en inglés), el cual integró información proveniente de la Lista Roja de Especies Amenazadas de la UICN, de los inventarios de campo sobre los usos locales de las especies vegetales, la distribución geográfica y calificaciones sobre la calidad del hábitat. En total, se usaron 281 levantamientos de vegetación en pastizales y 178 en bosques. En los pastizales, una alianza fitosociológica fue clasificada como críticamente amenazada, mientras que en los bosques tres alianzas fueron calificadas con un alto grado de amenaza. Si bien las categorías de la UICN permiten establecer comparaciones sobre el estado de conservación de las especies, éstas no reflejan de manera explícita las amenazas particulares que enfrentan los tipos de vegetación. Se propone que los modelos multicriterio para la evaluación de amenazas, ofrecen una visión integrada de los factores y del estado de conservación de cada tipo de vegetación, proporcionan un marco más integral para orientar las acciones de conservación. La evaluación de amenazas sobre los tipos de vegetación constituye un insumo clave en la definición de procesos de ordenamiento territorial, en la formulación de planes de manejo y en la administración de áreas protegidas.

**Palabras clave:** Sabanas neotropicales, Orinoquia colombiana, vegetación colombiana, amenazas a la flora y vegetación colombianas, Proceso Analítico Jerárquico (AHP)

In recent decades, the assessment of biodiversity threats has been predominantly guided by the criteria established by the International Union for Conservation of Nature (IUCN, 2020). Although the IUCN Red List of Threatened Species (RLTS) is widely recognized and applied to evaluate species-level threat statuses, it exhibits certain limitations when used to assess biodiversity at broader ecological scales—particularly at the level of plant communities. While the Red List includes multiple indicators of biotic diversity, species-specific evaluations are inherently limited

in their ability to capture the complexity and integrity of biodiversity as a whole. Moreover, the availability and quality of observational data are frequently constrained by a variety of factors, including environmental conditions, the technological capacity of field equipment, financial and logistical limitations, and the degree of stakeholder engagement. These challenges underscore the urgent need to develop integrative models capable of assessing biotic components across multiple spatial and organizational scales—especially at the level of phytocoenoses—within

1 Biology Program and Natural Sciences Services, Central University, Bogotá DC. 111711, Colombia. vminortac@ucentral.edu.co

2 Grupo de Investigación en Biodiversidad y Conservación, Instituto de Ciencias Naturales, Universidad Nacional de Colombia, Bogotá DC, Colombia.

3 UNELLEZ-Guanare, Programa de Ciencias del Agro y el Mar, Herbario Universitario (PORT), Mesa de Cavacas, estado Portuguesa 3350, Venezuela

4 Botany Unit, Faculty of Pharmacy, Complutense University of Madrid, 28040 Madrid, Spain; Department of Organismic and Evolutionary Biology, Harvard University Herbaria, Harvard University, Cambridge, MA 02138, USA.

both local and regional contexts. Such models are critical to informing long-term monitoring frameworks and the designation of priority conservation areas (Meng et al., 2020; Al-Qthanin et al., 2023). The progressive loss and fragmentation of vegetation cover pose serious threats to the spatial extent and ecological integrity of numerous primary habitats (Niño, 2018a, 2018b). In this context, the qualitative and quantitative characterization of land use and biodiversity—coupled with a robust understanding of the intensity and nature of human exploitation—constitutes a fundamental input for the development of more sophisticated methodologies for territorial zoning and spatial planning (Niño, 2018a).

An integrated, nationwide assessment of Colombia's biodiversity conservation status has not yet been completed. Most evaluations of threats to the country's flora have been carried out within its natural geographic regions through the foundational *Biodiversity Inventory Program of Colombia* (Rangel-Ch., 2014). At the species level, recent studies (Kor et al., 2022; López-Gallego and Morales-Morales, 2023; López-Gallego et al., 2024; Kor and Diazgranados, 2023; Kor et al., 2024) have analyzed major geographic, ecological, and taxonomic patterns of vascular plants assessed under the IUCN Red List criteria. These assessments currently encompass roughly 25% of Colombia's vascular flora and 57% of its endemic species. Importantly, these studies demonstrate that conservation status cannot be fully understood without accounting for socio-territorial dimensions—such as patterns of land use, traditional management practices, and local economic dependencies—which directly influence habitat integrity, species persistence, and the practical implementation of conservation strategies.

At the ecosystem level, classifications in Colombia have primarily followed the IUCN *Red List of Ecosystems* framework. Of the ecosystems assessed, 20 were categorized as Critically Endangered (CR), 18 as Endangered (EN), 15 as Vulnerable (VU), and 28 as Least Concern (LC) (IAvH, 2017). However, a persistent limitation lies in the scarcity of information at the level of vegetation communities. While extensive data are available for individual species and entire ecosystems, community-level assessments—particularly those concerning phytocoenoses, understood here as ecologically cohesive plant assemblages structured by environmental gradients and species interactions—remain considerably underdeveloped. Evaluations at this level, encompassing associations, alliances, and higher units within the phytosociological hierarchy, integrate floristic composition, structural attributes, and the ecological conditions that shape distinctive biophysical patterns. Yet, such approaches have not achieved sufficient methodological rigor or conceptual refinement to ensure consistent and comparable analyses across regions and

vegetation types.

In the Orinoquian region, these community-level dynamics are further constrained by long-standing anthropogenic pressures. Since the mid-20th century, rapid agricultural expansion, extensive cattle ranching, and extractive industries—especially oil and mineral exploitation authorized through governmental licensing—have profoundly altered the region's biophysical conditions, driving fragmentation of natural vegetation and reshaping the geographic distribution of numerous taxa (Mora-Fernández et al., 2015; Minorta-Cely and Rangel-Ch., 2014; Rátiva-G. et al., 2019a, 2019b; Rátiva-G. and Rangel-Ch., 2019). Consequently, advancing community-level analyses is imperative for assessing threats that emerge from the combined ecological and socio-territorial transformations shaping biodiversity and landscape integrity across the Orinoquia.

The Colombian-Venezuelan Llanos, encompassing approximately 532,000 km<sup>2</sup> (254,000 km<sup>2</sup> in Colombia and 278,000 km<sup>2</sup> in Venezuela), constitute the second-largest expanse of Neotropical savannas on the continent (Aymard, 2017; Piraquive-Bermúdez and Behling, 2022). This region is particularly notable for the diversity and floristic composition of its phytocoenoses, as well as the complexity of its ecological processes (Aymard, 2017). In Colombia, this ecoregion includes four National Natural Parks (El Tuparro, Serranía del Manacacias, Tinigua, and Sierra de La Macarena), one Integrated Management District (Cinaruco), and two additional areas currently undergoing protection processes (the Arauca Wetlands and the Transitional Forests of Cumaribo). Despite its ecological importance, the biodiversity of the Llanos is increasingly threatened by a range of anthropogenic pressures, including deforestation, mining, livestock grazing, the expansion of monocultures such as *Elaeis guineensis* Jacq. and various species belonging to the genera *Eucalyptus*, *Pinus*, and *Acacia*, as well as the proliferation of invasive species—particularly alien grasses such as *Cenchrus* spp., *Cynodon* spp., *Digitaria* spp., *Eleusine indica*, *Hyparrhenia* spp., *Megathyrsus maximus*, *Melinis* spp., and *Urochloa* spp. These disturbances exert profound impacts on the composition, structure, and spatial extent of plant communities and ecosystems in the region (Niño, 2019, 2025).

Building upon the recognition of widespread anthropogenic pressures on the Orinoquian landscape, several authors (Minorta-Cely and Rangel-Ch., 2014; Niño, 2018a, 2018b, 2019, 2025; Rátiva-G. et al., 2019a, 2019b) have highlighted that the application of criteria for assigning threat categories has often been constrained by limited and inconsistent field data on species populations and spatial distributions. Furthermore, structural variables of vegetation—such as cover, dominance (e.g., basal area), and density (e.g., number or abundance of individuals)—remain

frequently underutilized in conventional assessments, thereby limiting the precision of threat evaluations and weakening the reliability of conservation diagnostics. To address these limitations, these studies advocate for a more integrative evaluation framework incorporating complementary indicators such as species overexploitation, representativeness across the territory (e.g., number of collection localities), biological distinctiveness (endemism or taxonomic singularity), historical land-use transformations, and the projected impacts of infrastructure expansion. This expanded set of criteria not only enhances the methodological rigor of vegetation threat assessments but also fosters a more comprehensive understanding of the ecological and socio-environmental processes shaping the Orinoquian flora.

In the analysis of vegetation types, both the conservation status of vegetation units (e.g., forests, shrublands, and grasslands) and that of their surrounding environments were evaluated, incorporating the degree of representativeness (i.e., spatial distribution and extent) of each vegetation type within the study area. When forest or shrubland fragments were identified, the nature of the surrounding matrix—

whether natural, agricultural, or livestock-dominated—was also recorded to account for edge effects and habitat connectivity. Given that the drivers of transformation affecting plant communities are multifactorial and spatially heterogeneous, a comprehensive and objective assessment of threats required an integrative analytical approach. To this end, the AHP (Analytic Hierarchy Process) was applied as a robust decision-support tool for evaluating ecosystem threats. The AHP provided a structured, quantitative framework for weighting and prioritizing diverse environmental and anthropogenic factors based on expert judgment and consistency ratios, thereby reducing subjectivity in the assessment process. When integrated with field data information, this method enabled the generation of composite threat and vulnerability indices at multiple scales, revealing spatial patterns of ecological risk and conservation priority. By classifying these indices into ordinal levels, it was possible to filter data “noise,” enhance comparability among vegetation units, and produce a synoptic view of the ecological integrity and conservation status of the Orinoquian vegetation.

The aim of this article is to propose an Analytic

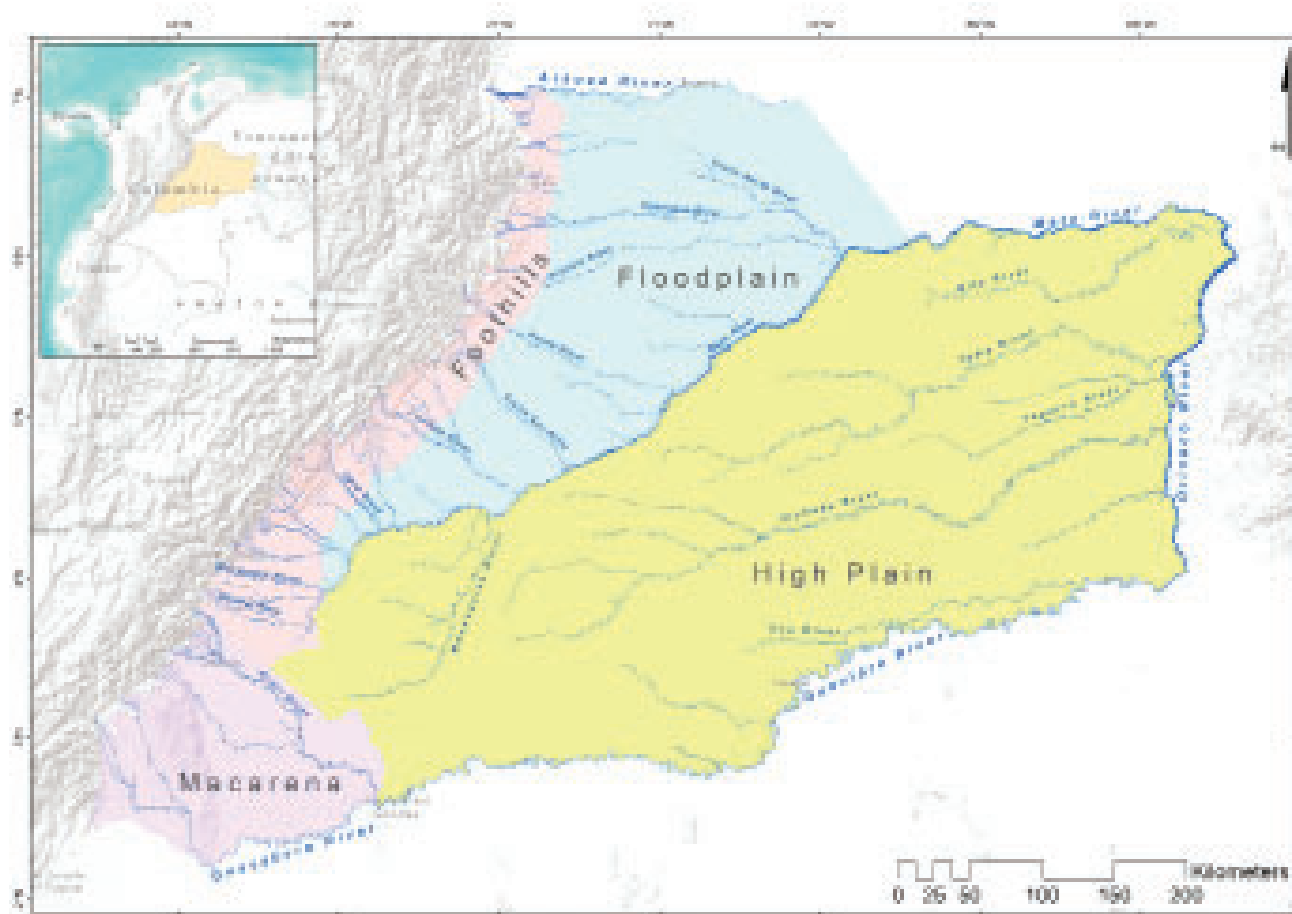


FIGURE 1: Study Area.

Hierarchy Process (AHP)-based model for assessing the threats affecting the vegetation of the Colombian Orinoquia, including both grasslands and forests. The model integrates IUCN guidelines (at the species level) with an evaluation of the ecological condition of the habitats where the vegetation occurs, along with an assessment of the potential uses of characteristic species within each described phytocoenosis by local human populations. Within this methodological framework, the following hypotheses are formulated: the degree of threat to a given vegetation type is expected to increase under the following conditions: (i) At least one of its dominant or characteristic species is classified under a threat category according to IUCN criteria; (ii) At least one dominant or characteristic species is subject to multiple uses, including timber or non-timber exploitation; and (iii) the habitat experiences critical levels of fragmentation or degradation. Accordingly, the proposed multicriteria model aims to support a more comprehensive evaluation of the nature and intensity of threats and to enable a more precise categorization of the conservation status of vegetation types. We posit that this procedure, which assigns differential weights to the various threat-related factors, will improve the accuracy of threat assessments and contribute to the design of conservation strategies that are contextually grounded in the sociocultural realities of the territories concerned.

#### MATERIALS AND METHODS

##### *Study Area*

The Colombian Orinoquia is in the eastern plains of the country and includes the localities of the Arauca, Casanare, Meta, and Vichada departments. Geographically, it extends from the foothills of the Eastern Cordillera in the west to the Orinoco River in the east, and from the Guaviare River in the south to the Arauca and Meta rivers on the northern border with Venezuela. Four physiographic units are recognized: the Foothills (referred to as *Piedemonte*), Alluvial Plains (referred to as *Llanura aluvial*), High Plains (referred to as *Altillanura*), and Sierra de La Macarena (Goosen, 1963; Blydenstein, 1967; Rippstein et al., 2001; Niño et al., 2023, 2025). Based on drainage characteristics and geomorphological processes, the region can be divided into two distinct units exhibiting different relief patterns: the well-drained Orinoquia (eastern Meta River, and the Meta and Vichada departments), characterized by high plains that are variously dissected, low hills, and different levels of terraces; and the poorly drained Orinoquia (western Meta River, and the Casanare and Arauca departments), characterized by alluvial fans and either alluvial or aeolic plains (Cortés, 1981; Fig. 1).

Phytosociological framework (Minorta-Cely et al., 2023a, 2023b, 2024). The phytosociological classification of the Orinoquian vegetation was established following the Braun-Blanquet approach, which organizes plant

communities hierarchically based on species composition, dominance, and floristic affinity. Under this framework, each community (association) is grouped into alliances, orders, and classes that reflect increasing ecological and floristic generality. The classification was established through quantitative and qualitative analyses of relevé data, considering the constancy and cover-abundance of diagnostic, differential, and characteristic species, as well as their spatial consistency across geographic gradients. The delineation of vegetation units or types further incorporated environmental variation associated with topography, soil texture, hydrological regime, and rainfall patterns.

Within the grassland formations, one class, three orders, and 19 alliances were identified. The class *Schizachyrio sanguinei–Trachypogonetea* spicati is widely distributed throughout the Orinoquian subregions, particularly across the high plains, margins of the alluvial plains, scattered areas of the aeolian plains, and occasionally along the foothill edges. This class encompasses three orders: i) *Axonopodo purpusi–Paspaletalia pectinati* (seven alliances), ii) *Schizachyrio brevifolii–Trachypogonetalia spicati* (five alliances), and iii) *Axonopodo purpusi–Andropogonetalia virgati* (seven alliances). In forests, three phytosociological classes were distinguished: i) Class *Maquiro coriaceae–Copaiferetea pubiflorae*, which includes the orders *Brosimo lactescentis–Oenocarpetalia minoris* (three alliances), *Iryanthero laevis–Oenocarpetalia batauae* (two alliances), *Alchorneo discoloris–Protietalia llanori* (five alliances), *Alibertio edulis–Mabeetalia trianae* (two alliances), and *Ocoteo bofo–Mabeetalia trianae* (three alliances). ii) Class *Brosimo lactescentis–Eschweileretea subglandulosae*, including the orders: *Mabeo nitidae–Mespilodaphnetalia cymbari* (two alliances), and *Phenakospermo guianensis–Minquartietalia guianensis* (one alliance). iii) Class *Jacarando copaiaae–Luehetea seemani*, represented by the order: *Pouterio stipitatae–Terminalietalia amazoniae* (two alliances). This hierarchical organization captures both floristic differentiation and ecological gradients within the Orinoquian landscape, thereby enabling a refined interpretation of vegetation patterns, their environmental drivers, and conservation priorities.

##### *Target Species Selection*

Species were selected based on the floristic composition tables compiled by Minorta-Cely et al. (2023a, 2023b). Selection criteria considered both dominances—expressed as percentage cover and basal area (m<sup>2</sup>)—and frequency, derived from their occurrence within the plant associations composing each alliance. The degree of threat for each species was subsequently determined using the IUCN Red List categories and criteria (2020; <https://www.iucnredlist.org/>). The assessment of species use followed the guidelines proposed by Rátiva-G. et al. (2019a, 2019b), which establish a multi-criteria framework for evaluating the intensity and

	IUCN	Uses	Field assessment	Alternative	Assessment	Weight	$\lambda$
IUCN	5	3	1	Critically endangered (CR)	1	0.63	3.07
				Endangered (EN)	0.8		
				Vulnerable (VU)	0.6		
				Near threatened (NT)	0.4		
				Least concern (LC)	0.2		
				Data deficient (DD)	0		
Uses	3	1	1/3	Timber	0.99	0.26	3.03
				Ornamental	0.83		
				Medicinal	0.66		
				Forage	0.49		
				Edible	0.33		
				Protective	0.16		
				Data deficient (DD)	0		
Field assessment	1	1/3	1/5	Endangered (EP)	0.99	0.11	3.01
				Near threatened (CA)	0.66		
				Least concern (PM)	0.33		
				Data deficient (DD)	0		

TABLE 1: Criteria for the categorization of threats to target species assessment and normalized priority matrix.

sustainability of plant resource exploitation. These guidelines incorporate parameters such as harvesting frequency, extraction purpose (e.g., timber, medicinal, ornamental), regeneration potential, and the socioeconomic dependence of local communities on each taxon. By integrating these criteria, the evaluation captures the functional and cultural relevance of species, thus strengthening the ecological interpretation of threat categories beyond purely biological indicators. In parallel, land-use and habitat-quality evaluations were incorporated through the spatial characterization of vegetation units and their surrounding matrices—classified as natural, agricultural, or livestock-dominated landscapes. These assessments considered habitat integrity, fragmentation patterns, accessibility, and the degree of anthropogenic disturbance. Field observations on land-use pressures, complemented by participatory dialogues with local residents, provided an empirical basis to refine conservation status assessments and contextualize them within the region's socio-territorial dynamics. This integration of ecological data and local knowledge enhanced the analytical rigor and territorial relevance of the threat evaluation framework, addressing limitations identified in previous studies.

#### *Analytic Hierarchy Process (AHP) Model*

The methodological guidelines and theoretical

considerations for this study are based on the methods recommended by Niño (2018a) and Saaty (1990, 1994). The AHP methodology unfolded in three steps: first, modeling or structuring the relevant variables for the evaluation to ensure a comprehensive consideration of pertinent factors; second, assessing or incorporating the evaluators' preferences through established judgments in a matrix of paired comparisons, allowing a systematic evaluation of criteria based on their importance; and third, prioritizing or calculating the weight vector of the criteria considered in the evaluation. This weight vector was then integrated with the criteria to calculate the threat level (Fülöp, 2004; Jiménez, 2002; Malczewski, 2006; Pulido-Herrera et al., 2024).

#### *First Step: AHP Input Data and Model Criteria*

We employed input data from the IUCN (2020) threat categories, along with threat characterizations developed by Rátiva-G. et al. (2019a, 2019b). The model additionally integrated information on species uses by local human communities, estimated threat levels derived from field-based observations of the dominance of natural or fragmented vegetation cover, as well as species' geographic distribution and commercial value (when applicable). Data on exploitation intensity and habitat quality were also incorporated into the model (Minorta-Cely and Rangel-

Ch., 2014; Niño, 2019; Rátiva-G. et al., 2019a, 2019b). Threat criteria and their relative importance were calibrated based on recorded threat levels and assigned standardized ordinal scores ranging from 0 to 1, according to the degree of risk. The final score for versatile species—defined by the number of documented uses per taxon—was calculated as the sum of points assigned to each recorded use category.

The dataset employed in this study integrates multiple sources of information: target species identified using a phytosociological framework (Minorta-Cely et al., 2023a, 2023b), their threat status as defined by the IUCN Red List (accessed December 2024, Appendix 1), records of human uses including extraction and exploitation (Rátiva-G. et al., 2019), and ecological field assessments conducted in representative vegetation units (Minorta-Cely and Rangel-Ch., 2014; Rátiva-G. et al., 2019a).

### *Second Step: AHP Criteria Weights*

A square matrix was constructed using paired comparisons to establish a correspondence scale linking qualitative assessments to numerical values (Alonso & Lamata, 2006; Saaty, 1990, 1994). This matrix of relative priorities incorporates ascending categories from the IUCN Red List, species uses, and field observations. Furthermore, a standard matrix was computed to estimate the weight vector for the criteria included in the anthropogenic classification of threats.

### *Third Step: AHP Criteria Integration and Threat Level Classification*

The weighting of each criterion was applied according to the assigned weights. The resulting score is the product of these values for each of the proposed alternatives or threat levels for each species. A weighted linear sum was calculated, resulting in a single threat score derived from the sum of the weighted criteria. This value was determined based on the weight assigned to each species and the total threats to species within their syntaxonomic categories. Finally, these values were classified using the natural breakout method (Niño, 2019). This methodology grouped the data based on its inherent characteristics, identifying ranges of similar values and maximizing the differences between categories.

## RESULTS

### *Model Fit and Validity*

Table 1 presents the normalized matrix used to calculate the weight vector of the criteria included in the vegetation threat assessment. The average eigenvalue ( $\lambda_{\max} = 3.039$ ) and the consistency ratio ( $CR = 0.037$ ) indicate acceptable coherence among judgments, ensuring reliability in the weighting process. The AHP provides an effective analytical framework for assessing explicit anthropogenic

pressures. By combining field data with expert judgment, this approach enhances the transparency and reproducibility of the evaluation. Threat categories were derived from the weighted aggregation of criteria, generating ordinal levels of conservation urgency (low, moderate, high, and very high risk). These levels represent relative differences in threat intensity: “high risk” indicates strong but potentially reversible pressures, while “very high risk” reflects ecosystems facing critical anthropogenic stress with minimal recovery potential. Among the evaluated criteria, the use criterion—reflecting extractive pressure, species versatility, and local dependency—had the highest relative weight. However, it must be interpreted in relation to other criteria, such as the IUCN Red List and habitat quality. While normalized values allow comparison within and across alliances, each criterion represents a distinct ecological dimension. The methodology overcomes the limitations of integrating threat and vulnerability on a single scale by evaluating them separately through ordinal indicators. This approach reduces statistical noise, improves ecological interpretation, and supports a robust, spatially coherent assessment of vegetation conservation status (Minorta-Cely, 2020; Niño, 2025).

### *Vegetation Threats Classification: Grassland Phytosociological Alliances (Minorta-Cely et al., 2023; Table 2)*

Seventeen phytosociological alliances were evaluated. In these phytocoenoses, the criterion with the highest rating corresponds to the use of characteristic species that define the syntaxa. The alliance *Paspalion carino-pectinati*, found in the high plains of the Serranía de Manacacías and extending into both the high plains and Sierra de La Macarena, was classified in the very high threat category. It obtained the highest values under the IUCN criterion (0.63), the use criterion (1.21), and the field-documented evidence criterion (0.35). The high threat category includes five alliances: *Sacciolepio angustissimatis*–*Rhynchanterion bracteatae*, predominantly distributed in the high plains, with its highest score under the IUCN criterion (0.38); *Hyptio brachiatae*–*Trachypogonion spicati* and *Sipaneo pratensis*–*Axonopodion purpusi*, occurring in both the high plains and Sierra de La Macarena; and *Eleochario interstinctae*–*Rhynchosporion barbatae*, all of which stand out due to the high use value (0.69) of their characteristic species. *Rhynchosporion barbatae*–*Axonopodion ancepitis*, distributed between the foothills and the alluvial plains, exhibits the highest number of characteristic species (21). The medium threat category includes four alliances, all confined to the foothills and alluvial plains: *Andropogono virgati*–*Axonopodion ancepitis*, *Axonopodo aurei*–*Trachypogonion spicati*, *Trichanthesio cyanescentis*–*Andropogonion virgati*, and *Caperonio palustris*–*Leersion hexandrae*. In three of these, the IUCN criterion score is zero. The low threat

Physiography	Phytosociological Alliances	T.T. SPP.	IUCN C.V.	U.C.V.	F.C.V.	Category
High Plains and La Macarena	<i>Paspalion carino-pectinati</i>	17	0.63	1.21	0.35	Very High
High Plains	<i>Sacciolepio angustissimatis–Rhynchanterion bracteatae</i>	8	0.38	0.26	0.18	
High Plains and La Macarena	<i>Hyptio brachiatae–Trachypogonion spicati</i>	10	0.13	0.69	0.18	
High Plains and La Macarena	<i>Sipaneo pratensis–Axonopodion purpuri</i>	10	0.00	0.69	0.18	High
Foothills and Alluvial Plains	<i>Eleochario interstinctae–Rhynchosporion barbatae</i>	10	0.25	0.69	0.25	
Foothills and Alluvial Plains	<i>Rhynchosporo barbatae–Axonopodion ancepitis</i>	21	0.25	0.43	0.25	
Foothills and Alluvial Plains	<i>Andropogono virgati–Axonopodion ancepitis</i>	8	0.00	0.39	0.11	
Foothills and Alluvial Plains	<i>Axonopodo aurei–Trachypogonion spicati</i>	8	0.00	0.43	0.11	Medium
Foothills and Alluvial Plains	<i>Caperonio palustris–Leersion hexandrae</i>	5	0.25	0.22	0.11	
Foothills and Alluvial Plains	<i>Trichantheo cyanescentis–Andropogonion virgati</i>	8	0.00	0.39	0.11	
High Plains	<i>Rhynchosporo corymbosae–Schizachyrion brevifoli</i>	7	0.13	0.09	0.11	
High Plains	<i>Schizachyrio brevifoli–Tibouchinon asperae</i>	6	0.13	0.04	0.04	
High Plains and La Macarena	<i>Hyptio confertae–Schizachyrion brevifoli</i>	4	0.13	0.09	0.11	Low
High Plains and La Macarena	<i>Hyptio lantanifoliae–Ichthyotherion terminalis</i>	6	0.00	0.09	0.07	
High Plains and La Macarena	<i>Paspalo pectinati–Axonopodion aurei</i>	4	0.00	0.17	0.04	
Foothills and Alluvial Plains	<i>Steinchismo laxae–Andropogonion bicornis</i>	5	0.00	0.22	0.07	
High Plains	<i>Xyrio savanensis–Coletanion caricoides</i>	6	0.00	0.00	0.00	Not Assessed

TABLE 2: Threat categories for grassland phytosociological alliances characterized in the Colombian Orinoquian region. T.T.SPP. (Total Target Species); IUCN C.V. (IUCN'S Criteria Value); U.C.V. (Use Criteria Value); F.C.V. (Field Criteria Value)

Physiography	Phytosociological Alliances/Formation	T.T. SPP.	IUCN C.V.	U.C.V.	F.C.V.	Category
High Plains	<i>Attaleo maripae–Irynterion laevis</i>	33	1.52	6.05	1.58	Very High
High Plains	<i>Guatterio hirsutae–Oenocarpus minoris</i>	43	2.91	7.39	2.17	
High Plains	<i>Protio guianensis–Caraipetion llanori</i>	42	2.66	6.01	1.75	
High Plains	<i>Caraipo llanori–Syagrion orinocensis</i>	21	0.76	3.55	0.98	
High Plains	<i>Protio aracouchinitis–Oenocarpion batauae</i>	19	2.03	2.42	0.84	
Foothills and Alluvial Plains	<i>Copaifero pubiflorae–Protion guianensis</i>	28	1.77	4.76	1.30	High
Alluvial Plains	<i>Spondiado mombinis–Viticion orinocensis</i>	18	1.14	3.37	0.84	
Alluvial Plains	<i>Vitidis orinocensis–Mabeetum trianae</i>	29	1.52	4.97	1.16	
Alluvial Plains and High Plains	<i>Coccolobo caracasanae–Tapiriretion guianensis</i>	11	0.89	2.21	0.60	Medium
Foothills and Alluvial Plains	<i>Ocoteo leptobotrae–Viticion orinocensis</i>	14	1.39	2.68	0.74	
Foothills and Alluvial Plains	<i>Phenakospermo guyannensis–Attaleion maripae</i>	14	0.89	2.12	0.63	
Foothills and High Plains	<i>Oenocarpo minoris–Attaleion maripae</i>	16	1.01	2.68	0.77	
High Plains	<i>Duguetio quitarensis–Amphirrhocion longifoliae</i>	16	1.27	1.51	0.60	
High Plains	<i>Siparuno guianensis–Maurition flexuosae</i>	14	0.63	1.77	0.46	
High Plains	<i>Virolo surinamensis–Mespilodaphnion cymbari</i>	10	0.89	1.86	0.53	
High Plains and La Macarena	<i>Bowdichio virgilioidis–Curatellion americanae</i>	17	1.39	2.64	0.70	
Alluvial Plains	<i>Protio heptaphylli–Jacarandion obtusifoliae</i>	6	0.00	0.95	0.21	
Foothills and Alluvial Plains	<i>Lueheo seemani–Pseudolmedion laevigatae</i>	5	0.38	1.17	0.32	
Foothills and Alluvial Plains	<i>Protio tenuifoli–Himathantion articulati</i>	3	0.25	0.65	0.18	
High plains	<i>Alchorneo triplinerviae–Maurition flexuosae</i>	5	0.38	0.91	0.25	
High Plains and La Macarena	<i>Gongylolepis martiana–Bonnetia sessilis</i>	14	0.13	0.00	0.04	Not Assessed
La Macarena	<i>Batocarpo orinocensis–Senefelderion verticillatae</i>	12	0.38	0.35	0.14	
La Macarena	<i>Chamaedoreo pinnatifrondis–Sloaneion brevispinae</i>	18	0.38	0.69	0.18	
La Macarena	<i>Micranda spruceana</i> and species of <i>Eschweilera</i>	15	0.76	1.56	0.39	
La Macarena	<i>Oenocarpus bataua–Protium rhoifolium</i>	9	0.25	0.61	0.18	
La Macarena	<i>Syagro orinocensis–Virolion elongatae</i>	12	0.25	1.04	0.28	

TABLE 3: Threat categories for forest phytosociological alliances characterized in the Colombian Orinoquian region. T.T.SPP. (Total Target Species); IUCN C.V. (IUCN'S Criteria Value); U.C.V. (Use Criteria Value); F.C.V. (Field Criteria Value).

category comprises six alliances, mostly restricted to the high plains: *Rhynchosporo corymbosae–Schizachyrion brevifolii*, *Schizachyrion brevifolii–Tibouchinon asperae*; shared between the high plains and Sierra de La Macarena: *Hyptio confertae–Schizachyrion brevifolii*, *Hyptio lantanifoliae–Ichthyotherion terminalis*, and *Paspalo pectinati–Axonopodion aurei*; and one (*Steinchismo laxae–Andropogonion bicornis*) found in both the foothills and alluvial plains. In three of these alliances, the IUCN criterion score is also zero. *Xyrio savanensis–Coletanion caricoides* is classified as having undetermined threat status due to insufficient data.

#### *Vegetation Threats Classification: Forest Phytosociological Alliances (Minorta-Cely et al., 2023a; Table 3)*

Twenty-six alliances were evaluated, but five of them (from Sierra de La Macarena) could not be assigned a rating due to insufficient data. As observed in the grasslands, the highest-rated criterion corresponds to the use of characteristic species that define the syntaxa—a direct consequence of selective logging and deforestation. Likewise, all alliances classified within the highest threat category are associated with the high plains. The “Very High Threat” category for the high plains subregion or landscape includes *Attaleo maripae–Iryantherion laevis*, *Guatterio hirsutae–Oenocarpion minoris*, and *Protio guianensis–Caraiption llanori*. The “High Threat” category includes many mixed palm groves and forest types such as *Caraipo llanori–Syagrion orinocensis*, *Protio aracouchinitis–Oenocarpion batauae* (high plains); *Copaifero pubiflorae–Protion guianensis* (foothills and alluvial plains); *Spondiadio mombinis–Viticion orinocensis*, and *Vitici orinocensis–Mabeetion trianae* in the floodplains. The “Medium Threat” category includes the forests of *Duguetio quitarensis–Amphirrhocion longifoliae*, *Siparuno guianensis–Mauritio flexuosae*, and *Virolo surinamensis–Mespilodaphnion cymbari* on high plains, as well as the palm groves of *Oenocarpion minoris–Attaleion maripae* (foothills and high plains); *Coccolobo caracasanae–Tapiriretion guianensis* in alluvial plains and high plains; *Ocoteo leptobotrae–Viticion orinocensis* and *Phenakospermo guyannensis–Attaleion maripae* in foothills and alluvial plains; and *Bowdichio virgilioidis–Curatellion americanae* in high plains and Sierra de La Macarena. The “Low Threat” category includes *Protio heptaphyllii–Jacarandion obtusifoliae* (alluvial plains); *Lueheo seemani–Pseudolmedion laevigatae* and *Protio tenuifolii–Himathantion articulati* (foothills and alluvial plains); and *Alchorneo triplinerviae–Mauritio flexuosae* (high plains).

#### DISCUSSION

The IUCN categories and criteria for assessing species

threat levels are largely taxonomic, focusing on individual species rather than on ecological or structural attributes of plant communities (Appendix 1). Although these criteria are useful for assessing impacts on local, regional, and global flora, they are less effective in capturing the dynamic and spatially heterogeneous processes that drive the degradation of vegetation types (Muñoz, 2013; Comer et al., 2022). In this study, we address these limitations by applying an AHP framework that evaluates threats based on both extrinsic (anthropogenic) and intrinsic (ecological) attributes. This integrative approach allows threats and vulnerabilities to be assessed independently, thereby reducing data noise and improving the traceability and reproducibility of classifications.

Compared to traditional IUCN assessments, our model explicitly quantifies the relative weight of diverse pressure factors, such as land-use intensity, habitat quality, and species exploitation. By normalizing and aggregating these criteria through the AHP process, we achieve a more balanced representation of how human and ecological variables interact across spatial scales. The improved accuracy is evidenced by the model’s ability to identify high-risk alliances in areas previously classified as stable under conventional assessments. For example, certain *Trachypogon*-dominated grassland alliances—typically considered of low conservation concern—were reclassified as highly threatened due to their strong exposure to fire regimes, soil compaction, and expansion of agropastoral matrices.

In forests, the results reveal a clear positive relationship between species richness, the number of characteristic taxa defining each syntaxon, and their final threat classification. Conversely, in grasslands, the non-linear relationship among these variables reflects historical gaps in knowledge, particularly for herbaceous species of low commercial interest. Spatially, the model detects high and very high threat levels concentrated in the foothills, where intensive agriculture, mining, and urban expansion exert severe pressure. In contrast, the high plains exhibited moderate to low threat levels, with localized hotspots of high risk. These results emphasize that threat assessment models integrating hierarchical vegetation classification with multicriteria evaluation not only enhance accuracy and ecological realism but also provide a more reliable foundation for conservation planning and the establishment of new protected areas in the Orinoquia region.

#### *Threats Categorization*

Threat assessments concerning vegetation habitat conditions and floristic composition are grounded in field surveys and systematic observations. However, field-based results must be critically reviewed in light of species’ geographic distributions and ecological attributes

to appropriately adjust or reclassify taxa within threat categories. This need arises from widespread degradation and environmental change occurring at regional scales over the past six decades—both globally and in the Orinoquian region specifically. Taxonomic turnover implies a near-complete functional reorganization of ecological assemblages, leading to the emergence of novel configurations of ecosystem services and disservices, particularly within human-modified landscapes (Filgueiras et al., 2021). This context underscores the urgency of implementing targeted conservation strategies, especially in areas experiencing substantial ecological pressures. The methodology used to evaluate vegetation integrates ecological data collection, plot-based field assessments, and expert validation, thereby providing a rigorous and operational framework for identifying priority areas for conservation and ecological intervention.

#### *Threats Assessment*

Threat assessments related to the floristic composition of vegetation types and habitat conditions were based on field research and detailed ecological observations. The results of field inventories were thoroughly reviewed and refined by considering the geographic distribution and ecological attributes of the recorded species, in order to achieve more accurate threat ratings. This complementary process was driven by the recognition of ongoing environmental degradation and large-scale ecological transformations in the Orinoquia region over the past six decades. Taxonomic replacement often entails an almost complete functional reorganization of ecological assemblages, accompanied by the emergence of novel ecosystem services—including those associated with human-modified landscapes (Filgueiras et al., 2021). The methodology employed for threat assessment integrated ecological data collection, field

plot evaluations, and expert validation, thereby offering a rigorous and operational framework for identifying priority areas for intervention. It also underscores the urgent need for targeted conservation strategies in regions under significant anthropogenic pressure.

#### *Threats to Flora and Vegetation*

Previous studies (Rangel-Ch., 2014; Kor et al., 2022; López-Gallego and Morales-Morales, 2023; López-Gallego et al., 2024; Kor and Diazgranados, 2023) have reported a higher number of threatened species in the Orinoquia region compared to other natural regions of Colombia. A preliminary assessment and classification of the threats affecting vegetation types in this region was conducted by Minorta-Cely and Rangel-Ch. (2014) and Rátiva-G. et al. (2019a, 2019b). In our contribution on grassland vegetation, 16 out of the 17 characterized alliances were classified as presenting some degree of threat. In forest vegetation, four alliances were categorized as “Very High,” ten as “High,” and 12 as “Medium” threat level. All physiographic units of the Orinoco territory include at least one vegetation type in a state of significant concern, underscoring the urgent need to implement targeted conservation measures. Particularly noteworthy is the vegetation of the Sierra de La Macarena, which warrants special attention, as several of its phytocoenoses could not be assessed due to the lack of floristic and ecological data from the specific geographic sectors in which they occur (see Table 4).

#### *Implications and Limitations for Conservation*

Threats to the vegetation of the grasslands and forests of the Orinoco region stem from direct habitat modification and other anthropogenic practices rooted in the region’s social and cultural context. These threats, which possess significant and multi-scalar implications, encompass biotic, social, political, and cultural dimensions. Therefore,

Physiography	Assessments of Forest Alliances				Assessments of Grassland Alliances					
	Very High	High	Medium	Low	Not Assessed	Very High	High	Medium	Low	Not Assessed
La Macarena					5					
Alluvial Plains		2		1						
Alluvial Plains and High Plains			1							
Foothills and Alluvial Plains		1	2	2			2	4	1	
Foothills and High Plains			1							
High Plains	3	2	3	1			1		2	1
High Plains and La Macarena			1		1	1	2		3	

TABLE 4: Phytosociological alliances evaluated (AHP-Model) in the physiographic units of the Colombian Orinoquia.

it is essential to evaluate how traditional (sustainable) practices and extractive (unsustainable) uses influence the conservation status of these ecosystems. A precise classification of the impacts of landscape transformation—such as land conversion for agriculture, urban expansion, or the fragmentation of contiguous natural vegetation—is required to understand changes in the geographic distribution and richness of plant communities.

The proposed methodological model is a valuable tool for identifying priority conservation areas and informing formal conservation declarations. Based on the results obtained, the geographic zones of the Sierra de La Macarena where the *Paspalion carino-pectinati* grasslands and the forests belonging to the *Attaleo maripae–Iryantherion laevis*, *Gutterio hirsutae–Oenocarpion minoris*, and *Protio guianensis–Caraipetion llanori* alliances are found should be considered suitable for the implementation of active biodiversity and territorial conservation programs. There is an urgent need to document, assess, and address how species richness, uniqueness, and distinctiveness of syntaxa vary according to the ecological particularities of each territory. These dimensions should carry significant weight in guiding the implementation of conservation actions or strategies that go beyond species richness values alone.

In this context, it is noteworthy that the findings of this study provide the technical basis for the designation of new protected areas, including the Serranía del Manacacias National Natural Park (Meta highlands), the Arauca Wetlands Complex (floodplain, Arauca), and the Cumaribo Transitional Forests (Amazon–Orinoquia ecotone).

#### CONCLUSIONS

The application of the AHP method has proved to be an effective analytical instrument for evaluating spatially explicit ecosystem threats. By independently integrating indices of threat and vulnerability and minimizing statistical “noise” through the ordinal classification of indicators, the model provided a more objective assessment of ecological integrity and conservation status. Results revealed that in the foothills unit, high and very high threat levels predominated, primarily associated with intensive agriculture, mineral extraction, and human occupation of alluvial fans. In contrast, the high plains exhibit low to moderate threat levels, with localized hotspots of high risk. These spatial patterns underscore the importance of conducting vegetation health assessments at appropriate geographic scales to better understand the vegetation’s capacity to provide environmental services.

Our three hypotheses were fully supported. First, vegetation alliances containing at least one dominant or characteristic species categorized under an IUCN threat level consistently corresponded to higher composite threat scores in our model. Second, vegetation units dominated

by species subjected to multiple use pressures—especially timber and non-timber exploitation—exhibited higher vulnerability indices, confirming the strong influence of human use intensity. Third, habitats experiencing advanced fragmentation or degradation (e.g., within agricultural and cattle-raising matrices) were consistently ranked in the “High” or “Very High” threat categories, demonstrating the model’s sensitivity to spatial disturbance metrics.

These findings validate the capacity of the proposed multicriteria model to integrate biophysical and socioecological variables and to identify subtle gradients of degradation that may not be captured by conventional IUCN ecosystem assessments. By assigning differential weights to diverse information sources—species-level data, local ecological attributes, habitat quality, and land-use pressures—the model avoids linear simplifications, acknowledging that conservation pressures vary by territory and are strongly shaped by historical land-use trajectories.

In grasslands, the model’s outcomes are consistent with the ecological characterization of the *Schizachyrio sanguinei–Trachypogonetea spicati* class. Dominant and characteristic species such as *Paspalum carinatum*, *Andropogon virgatus*, *Axonopus anceps*, and *Schizachyrium brevifolium* exemplify functional traits linked to fire tolerance and soil compaction, which correspond with higher threat ratings. In forests, the model corroborates the high-threat status of the *Copaifero pubiflorae–Protion guianensis* alliance, where dominant taxa (*Protium guianense*, *Spondias mombin*, *Vitex orinocensis*, *Mauritia flexuosa*) coincide with the most severe degradation patterns. Collectively, these results highlight that the AHP framework enhances the precision of threat classification by explicitly linking hypotheses, species attributes, and landscape-scale pressures—thus providing a reproducible and ecologically grounded tool for conservation planning in the Orinoquia region.

#### ACKNOWLEDGMENTS

We extend our sincere gratitude to Francisco Castro-Lima, Daniela Rátiva-Gaona, and Francisco Mijares for their valuable collaboration in establishing floristic and vegetation plots and for their essential support during fieldwork and taxonomic species identification. We also express our appreciation to the local research partners and field assistants for their commitment and assistance throughout the study. Special thanks are due to the *Parques Nacionales Naturales de Colombia* (PNN) system for their logistical and institutional support.

## LITERATURE CITED

- AL-QTHANIN, R. N., AND S. A. ALHARBI. 2023. Regional conservation assessment of the Threatened Species: A Case study of twelve plant species in the Farasan Archipelago. *Conservation* 3(1): 127–152. <https://doi.org/10.3390/conservation3010011>
- ALONSO, J., AND L. M. LAMATA. 2006. Consistency in the analytic hierarchy process: A new approach. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* 14(4): 445–459.
- AYMARD, G. 2017. Adiciones a la flora vascular de los llanos de venezuela: nuevos registros y estados taxonómicos. *BioLlania Edición Especial* 15: 1–296. <http://revistas.unellez.edu.ve/index.php/biollania/issue/view/36>
- BLYDENSTEIN, J. 1967. Tropical savanna vegetation of the llanos of Colombia. *Ecology* 48: 115.
- COMER, P. J., J. C. HAK, AND P. MCINTYRE. 2022. Addressing climate change vulnerability in the IUCN Red List of Ecosystems—results demonstrated for a cross-section of major vegetation-based ecosystem types in the United States. *Land* 11: 302. <https://doi.org/10.3390/land11020302>
- CORTÉS-L., A. 1981. Capacidad de uso actual y futuro de las tierras de la Orinoquia colombiana: un enfoque ecológico. *Boletín de la Sociedad Venezolana de Ciencias Naturales* 139: 427–448.
- FILGUEIRAS, B. K. C., C. A. PERES, F. P. L. MELO, I. R. LEAL, AND M. TABARELLI. 2021. Winner–loser species replacements in human-modified landscapes. *Trends in Ecology & Evolution* 36(6): 545–555. <https://doi.org/10.1016/j.tree.2021.02.006>
- FÜLÖP, J. 2004. Introduction to decision making methods. *Workshop 3*: 1–15.
- GOOSEN, D. 1963. División fisiográfica de los Llanos Orientales. *Revista Nacional de Agricultura* 55: 39–41.
- Instituto Alexander von Humboldt. 2017. Actualización de la lista roja de ecosistemas terrestres de Colombia. <https://reporte.humboldt.org.co/biodiversidad> (accessed December 2024).
- IUCN. 2020. *Guidelines for Using the IUCN Red List Categories and Criteria*. Version 13. Prepared by the Standards and Petitions Subcommittee. <http://cmsdocs.s3.amazonaws.com/RedList%20Guidelines.pdf> (accessed December 2024).
- JIMÉNEZ, J. A. 2002. El proceso analítico jerárquico (AHP): fundamentos, metodología y aplicaciones. *Rect@ Revista Electrónica de Comunicaciones y Trabajos de ASEPUMA* 1: 28–77.
- KOR, L., C. LÓPEZ-GALLEGO, C. CASTELLANOS-CASTRO, AND M. DÍAZGRANADOS. 2022. Assessing extinction risk coverage and identifying geographical hotspots to guide conservation action for Colombia's useful plants. Pages 35–48 in R. NEGRÃO, A. MONRO, C. CASTELLANOS-CASTRO, AND M. DÍAZGRANADOS, eds., *Useful Plants of Colombia*. Royal Botanic Gardens, Kew, London.
- KOR, L., M. FERNÁNDEZ-LUCERO, D. A. GRANADOS FLÓREZ, T.P. DAWSON, AND M. DIAZGRANADOS. 2024. Bridging local and scientific knowledge for area-based conservation of useful plants in Colombia. *Ambio* 53: 309–323. <https://doi.org/10.1007/s13280-023-01921-5>
- KOR, L. AND M. DÍAZGRANADOS. 2023. Identifying important plant areas for useful plant species in Colombia. *Biological Conservation* 284: 110187. <https://doi.org/10.1016/j.biocon.2023.110187>
- LÓPEZ-GALLEGO, C. AND P. A. MORALES-MORALES. 2023. The Red List for the endemic trees of Colombia: effective conservation targeted for plants required in biodiversity hotspots. *Plants, People, Planet* 5(4): 617–627. <https://doi.org/10.1002/ppp3.10360>
- LÓPEZ-GALLEGO, C., P. A. MORALES-MORALES, C. CASTELLANOS-CASTRO, N. SALINAS, J. AGUIRRE-SANTORO, A. APONTE, J. BETANCUR, O. DÍAZ-VASCO, M. DÍAZGRANADOS-CADELO, AND D. HIGUERA-DÍAZ. 2024. Avances en la Lista Roja de las plantas de Colombia. *Biota* 25: e1175.
- MALCZEWSKI, J. 2006. GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science* 20: 703–726. <https://doi.org/10.1080/13658810600661508>
- MENG, X., H. HUANG, L. GUO, D. WANG, R. HAN, AND K. ZHOU. 2020. Threatened status assessment of multiple grassland ecosystems and conservation strategies in the Xilin River Basin, NE China. *Sustainability* 12(3): 1084. <https://doi.org/10.3390/su12031084>
- MINORTA-CELY, V. 2020. La vegetación de la Orinoquia colombiana: riqueza, diversidad y conservación. Ph.D. diss., Instituto de Ciencias Naturales, Universidad Nacional de Colombia.
- MINORTA-CELY, V., AND J. O. RANGEL-CH. 2014. Amenazas a la Flora, la vegetación y los ecosistemas de la Orinoquia colombiana. Pages 785–806 in J. O. RANGEL-CH. ed., *Colombia Diversidad Biótica. La Región de la Orinoquia de Colombia*. Universidad Nacional de Colombia, Instituto de Ciencias Naturales, Bogotá DC, Colombia.
- MINORTA-CELY, V., J. O. RANGEL-CH., F. CASTRO-L., AND G. AYMARD. 2023a. Los bosques de la Orinoquia colombiana. Pages 413–587 in J. O. RANGEL-CH, ed., *Colombia Diversidad Biótica. Tipos de vegetación en las regiones naturales de Colombia. Nuevos Aportes*. Universidad Nacional de Colombia, Instituto de Ciencias Naturales, Bogotá DC, Colombia.
- MINORTA-CELY, V., J. O. RANGEL-CH., F. CASTRO-L., AND G. AYMARD. 2023b. Los pastizales de la Orinoquia colombiana. Pages 305–412 in J. O. RANGEL-CH, ed., *Colombia Diversidad Biótica. Tipos de vegetación en las regiones naturales de Colombia. Nuevos Aportes*. Universidad Nacional de Colombia, Instituto de Ciencias Naturales, Bogotá DC, Colombia.
- MINORTA-CELY, V., L. NIÑO, O. RANGEL, AND D. SÁNCHEZ-MATA. 2024. Environmental factors influencing species richness expression in grasslands of the Colombian Orinoquia. *Plants* 13: 3545. <https://doi.org/10.3390/plants13243545>
- MORA-FERNÁNDEZ, C., L. PEÑUELA-RECIO, AND F. CASTRO-LIMA. 2015. Estado del Conocimiento de los Ecosistemas de las Sabanas Inundables en la Orinoquia Colombiana. *Orinoquia* 19: 253–271.
- MUÑOZ, L., AND V. H. HAUSNER. 2013. What do the IUCN

- categories really protect? A case study of the alpine regions in Spain. *Sustainability* 5: 2367–2388. <https://doi.org/10.3390/su5062367>
- NIÑO, L. 2018a. *Aproximación geográfica de las condiciones de amenaza sobre la vegetación: zonificación multicriterio de tres áreas en declaratoria de protección, localizadas en la Orinoquia colombiana*. Tesis de Maestría, Universidad Nacional de Colombia, Instituto de Ciencias Naturales.
- NIÑO, L. 2018b. Zonificación minera basada en la integración de la evaluación ambiental estratégica y modelado con múltiples criterios en la región de La Macarena, departamento del Meta, Orinoquia colombiana. *BioLlania Edición Especial* 15: 634–666. <http://revistas.unelvez.edu.ve/index.php/biollania/issue/view/36>
- NIÑO, L. 2019. Aspectos cartográficos de la vegetación, los ecosistemas y las amenazas en la Serranía de Manacacías (Meta) Orinoquia colombiana. Pages 573–600 in J. O. RANGEL-CH., G. ANDRADE-C., C. JARRO-F., Y G. SANTOS-C., eds., *Colombia Diversidad Biótica. La Región de la Serranía de Manacacías (Meta) Orinoquia Colombiana*. Vol. 17. Universidad Nacional de Colombia, Instituto de Ciencias Naturales, Bogotá DC, Colombia.
- NIÑO, L., A. JARAMILLO, V. VILLAMIZAR, AND J. O. RANGEL-CH. 2023. Geomorphology, land-use, and hemeroby of foothills in Colombian Orinoquia: classification and correlation at a regional scale. *Papers in Applied Geography*. <https://doi.org/10.1080/23754931.2023.2189921>
- NIÑO, L. 2025. *Los ecosistemas de la Orinoquia colombiana: estado de salud, conservación y oferta ambiental*. Ph.D. diss., Universidad Nacional de Colombia, Instituto de Ciencias Naturales.
- PIRAQUIVE-BERMÚDEZ, D., AND H. BEHLING. 2022. Holocene paleoecology in the Neotropical savannas of northern South America (Llanos of the Orinoquia ecoregion, Colombia and Venezuela): what do we know and on what should we focus in the future? *Frontiers in Ecology and Evolution* 10: 824–873. <https://doi.org/10.3389/fevo.2022.824873>
- POLLOCK, L. J., L. M. O'CONNOR, K. MOKANY, D. F. ROSAUER, M. V. TALLUTO, AND W. THULLER. 2020. Protecting biodiversity (in all its complexity): new models and methods. *Trends in Ecology & Evolution* 35: 1119–1128. <https://doi.org/10.1016/j.tree.2020.08.015>
- PULIDO-HERRERA, L. A., C. SEPÚLVEDA, J. A. JIMÉNEZ, J. E. BETANZOS-SIMÓN, E. PÉREZ-SÁNCHEZ, AND L. NIÑO. 2024. Landscape connectivity in extensive livestock farming: an adaptive approach to the land sharing and land sparing dilemma. *Frontiers in Sustainable Food Systems* 8: 1–16. <https://doi.org/10.3389/fsufs.2024.1345517>
- Rangel-Ch., J.O. (ed.). 2014. *Colombia Diversidad Biótica XIV. La región de la Orinoquia de Colombia*. Universidad Nacional de Colombia - Instituto de Ciencias Naturales. 847pp. Bogotá D.C.
- RÁTIVA-G., D., AND J. O. RANGEL-CH. 2019. Usos y amenazas para la conservación de las plantas con flores del territorio Sabanas y Humedales de Arauca. Pages 473–494 in J. O. RANGEL-CH., G. ANDRADE-C., C. JARRO-F., AND G. SANTOS-C., eds., *Colombia Diversidad Biótica. Territorio Sabanas y Humedales de Arauca (Colombia)*. Universidad Nacional de Colombia, Instituto de Ciencias Naturales, Bogotá DC, Colombia.
- RÁTIVA-G., D., J. O. RANGEL-CH., G. AYMARD, AND A. G. CONCHA-M. 2019a. Usos potenciales y categorías de riesgo de las plantas con flores en el territorio de las selvas transicionales de Cumaribo, Vichada (Colombia). Pages 397–426 in J. O. RANGEL-CH., G. ANDRADE-C., C. JARRO-F., AND G. SANTOS-C., eds., *Colombia Diversidad Biótica. Selvas transicionales de Cumaribo (Vichada-Colombia)*. Universidad Nacional de Colombia, Instituto de Ciencias Naturales, Bogotá DC, Colombia.
- RÁTIVA-G., D., J. O. RANGEL-CH., A. G. CONCHA-M., AND V. MINORTA-CELY. 2019b. Patrones de uso y amenazas a la flora y la vegetación de la Serranía de Manacacías (Meta) Orinoquia colombiana. Pages 359–384 in J. O. Rangel-Ch., G. Andrade-C., C. Jarro-F., and G. Santos-C., eds., *Colombia Diversidad Biótica. La Región de la Serranía de Manacacías (Meta) Orinoquia Colombiana*. Universidad Nacional de Colombia, Instituto de Ciencias Naturales, Bogotá DC, Colombia.
- RIPPSTEIN, G., G. ESCOBAR, AND F. MOTTA, eds. 2001. *Agroecología y biodiversidad de las sabanas en los Llanos Orientales de Colombia*. CIAT and CIRAD, Cali.
- SAATY, T. 1990. How to make a decision: the analytic hierarchy process. *European Journal of Operational Research* 48(1): 9–26.
- SAATY, T. 1994. How to make a decision: the analytic hierarchy process. *Interfaces* 24(6): 19–43. Colombian Orinoquia.

## APPENDIX 1

## SPECIES THREAT CLASSIFICATION UNDER IUCN CRITERIA

Appendix 1A: Species categorized as medium threat according to IUCN criteria in grasslands.

*Aristolochia nummularifolia*, *Axonopus anceps*, *Byrsonima crassifolia*, *Byrsonima verbascifolia*, *Miconia dependens*, *Miconia rubra*, *Clitoria guianensis*, *Crotalaria pilosa*, *Cuphea melvilla*, *Eleocharis geniculata*, *Eragrostis maypurensis*, *Eriosema crinitum*, *Heliconia psittacorum*, *Hyptis recurvata*, *Hyptis brachiata*, *Hyptis dilatata*, *Kyllinga odorata*, *Torenia crustacea*, *Miconia rubiginosa*, *Mimosa xanthocentra*, *Nymphoides indica*, *Panicum cayennense*, *Paspalum maculosum*, *Panicum rudgei*, *Paspalum repens*, *Rhynchospora candida*, *Rhynchospora corymbosa*, *Rotala mexicana*, *Sacciolepis angustissima*, *Scleria distans*, *Scleria reticularis*, *Setaria parviflora*, *Sida serrata*, *Sphenoclea zeylanica*, *Utricularia gibba*, *Utricularia subulata*, *Zornia diphylla*, *Bacopa reptans*, *Bacopa salzmannii*, *Caperonia palustris*, *Eriocaulon melanocephalum*, *Ludwigia sedioides*, *Paspalum carinatum*, *Sauvagesia deflexifolia*, *Sauvagesia erecta*, *Vandellia diffusa*, *Xyris savanensis*.

## Appendix 1B: Species categorized as low threat according to IUCN criteria in grasslands.

*Acanthospermum australe, Acisanthera limnobios, Acisanthera quadrata, Acisanthera uniflora, Acmella brachyglossa, Aeschynomene elegans, Aeschynomene evenia, Aeschynomene paniculata, Amaranthus dubius, Ambrosia peruviana, Andropogon hypogynus, Andropogon lateralis, Andropogon leucostachyus, Andropogon selloanus, Aristida capillacea, Aristida torta, Axonopus aureus, Axonopus compressus, Buchnera jacoborum, Buchnera palustris, Buchnera rosea, Bulbostylis junciformis, Bulbostylis lanata, Burmannia bicolor, Burmannia capitata, Byttneria genistella, Calea tolimana, Centrosema angustifolium, Chelonanthus alatus, Cipura paludosa, Coleataenia caricoides, Crotalaria incana, Crotalaria maypurensis, Crotalaria sagittalis, Crotalaria velutina, Ctenium concissum, Cuphea antisiphilitica, Cuphea odonellii, Cuphea repens, Curatella americana, Curtia tenuifolia, Cyperus aggregatus, Cyperus luzulae, Declieuxia fruticosa, Desmodium incanum, Desmoscelis villosa, Dioscorea amazonum, Dorstenia brasiliensis, Echinolaena inflexa, Eleocharis acutangula, Eleocharis filiculmis, Eleocharis interstincta, Eleocharis minima, Elephantopus mollis, Eriochrysis cayennensis, Eriochrysis laxa, Eriope crassipes, Eryngium foetidum, Galactia jussiaeana, Gymnopogon fastigiatus, Heliotropium indicum, Heteranthera limosa, Hibiscus sabdariffa, Hyptis conferta, Hyptis lantanifolia, Imperata brasiliensis, Indigofera lespedezioides, Ipomoea argentea, Kyllinga brevifolia, Larentia linearis, Limnosipanea spruceana, Ludwigia erecta, Ludwigia nervosa, Ludwigia rigida, Mandevilla scabra, Alectra stricta, Melochia nodiflora, Melochia spicata, Melochia villosa, Merremia aturensis, Miconia borjensis, Miconia rufa, Microstachys corniculata, Mikania congesta, Mimosa pellita, Murdannia nudiflora, Neanotis lancifolia, Panicum pilosum, Panicum trichoides, Paspalum lanciflorum, Paspalum melanospermum, Paspalum morichalense, Paspalum multicaule, Paspalum parviflorum, Paspalum pectinatum, Paspalum stellatum, Paspalum trinitense, Perama dichotoma, Philodice hoffmannseggii, Phyllanthus hyssopifolioides, Phyllanthus stipulatus, Piriqueta cistoides, Polygala paniculata, Polygala timoutou, Pterogastrea minor, Rhynchospora albescens, Rhynchospora barbata, Rhynchospora cephalotes, Rhynchospora emaciata, Rhynchospora globosa, Sacciolepis myuros, Sauvagesia tenella, Schiekia orinocensis, Schultesia brachyptera, Schwenckia americana, Scleria microcarpa, Sida glomerata, Sipanea hispida, Sipanea pratensis, Solanum jamaicense, Sorghastrum setosum, Spermacoce capitata, Spermacoce verticillata, Sporobolus jacquemontii, Steinchisma laxa, Stephostachys mertensii, Stylosanthes guianensis, Syngonanthus caulescens, Thalia geniculata, Trachypogon spicatus, Trichantheicum cyanescens, Turnera scabra, Turnera ulmifolia, Urochloa decumbens, Vouarana guianensis, Xyris jupicai.*

## Appendix 1C: Species categorized as very high threat according to IUCN criteria in forests.

*Abarema jupunba*, *Alchornea triplinervia*, *Andira inermis*, *Andira surinamensis*, *Aniba panurensis*, *Annona ambotay*, *Aspidosperma desmanthum*, *Aspidosperma excelsum*, *Aspidosperma spruceanum*, *Bocageopsis multiflora*, *Terminalia macrophylla*, *Terminalia viridiflora*, *Byrsonima japurensis*, *Caraipa densifolia*, *Cassia moschata*, *Clarisia biflora*, *Clarisia racemosa*, *Cupania scrobiculata*, *Duguetia cauliflora*, *Duguetia macrophylla*, *Duguetia odorata*, *Duroia eriopila*, *Duroia micrantha*, *Ficus albert-smithii*, *Ficus americana* subsp. *guianensis*, *Ficus dendrocida*, *Ficus donnell-smithii*, *Ficus insipida*, *Ficus mathewsii*, *Ficus maxima*, *Ficus obtusifolia*, *Ficus trigona*, *Guarea glabra*, *Guarea pubescens*, *Guatteria hirsuta*, *Guatteria inundata*, *Guatteria liesneri*, *Guatteria schomburgkiana*, *Henriettea* cf. *goudotiana*, *Hieronyma alchorneoides*, *Hirtella elongata*, *Hymenopus heteromorphus*, *Inga alba*, *Inga brachyrhachis*, *Inga cylindrica*, *Inga heterophylla*, *Inga ingoides*, *Inga interrupta*, *Inga marginata*, *Inga psittacorum*, *Lacmellea edulis*, *Leptobalanus apetalus*, *Licania hypoleuca*, *Licania kunthiana*, *Leptobalanus longistylus*, *Mabea piriri*, *Maclura tinctoria*, *Matayba elegans*, *Mouriri guianensis*, *Nectandra aurea*, *Ocotea puberula*, *Parinari excelsa*, *Parkia discolor*, *Parkia nitida*, *Perebea xanthochyma*, *Protium glabrescens*, *Protium guianense*, *Samanea saman*, *Sapium glandulosum*, *Sarcaulus brasiliensis*, *Sorocea muriculata*, *Sorocea sprucei*, *Sorocea steinbachii*, *Sterculia apetalata*, *Virola carinata*, *Virola elongata*, *Virola pavonis*, *Virola sebifera*, *Virola surinamensis*, *Vismia baccifera*, *Vitex compressa*, *Vochysia lehmannii*, *Vochysia obscura*, *Xylopia discreta*, *Xylopia emarginata* and *Xylopia sericea*.

## Appendix 1D: Species categorized as high threat according to IUCN criteria in forests.

*Alchornea discolor, Alchornea fluviatilis, Aniba cylindriflora, Annona montana, Apuleia leiocarpa, Brosimum rubescens, Brownea coccinea, Bursera simaruba, Myrcia aulomyrcioides, Aiouea montana, Clathrotropis macrocarpa, Cupania latifolia, Duguetia riberensis, Duroia fusifera, Duroia hirsuta, Endlicheria multiflora, Erythrina fusca, Eugenia florida, Genipa americana, Guarea cristata, Guatteria punctata, Hieronyma oblonga, Hydrochorea corymbosa, Jacaranda caucana, Jacaranda obtusifolia, Lacmellea floribunda, Lacmellea foxii, Leptolobium nitens, Licania canescens, Maquira calophylla, Matayba arborescens, Micropholis venulosa, Moquilea subarachnophylla, Myrcia bracteata, Myrcia guianensis, Myrcia paivae, Myrcia splendens, Myrcia subsessilis, Myrciaria floribunda, Nectandra cuspidata, Nectandra globosa, Nectandra membranacea, Ocotea amazonica, Ocotea floribunda, Ocotea longifolia, Ocotea oblonga, Ormosia macrocalyx, Panopsis rubescens, Parahancornia oblonga, Perebea mollis, Pouteria cuspidata, Pouteria elegans, Pouteria glomerata, Pouteria gomphiifolia, Pouteria multiflora, Pouteria stipitata, Protium amazonicum, Protium crassipetalum, Protium laxiflorum, Protium sagotianum, Protium stevensonii, Protium unifoliolatum, Psidium guineense, Annona exsucca, Sapium jenmannii, Sloanea terniflora, Trattinnickia aspera, Trattinnickia lawrancei, Trichilia elegans, Trichilia hirta, Trichilia pallida, Trichilia pleeana, Trichilia quadrijuga, Trymatococcus amazonicus, Virola schultesii, Vismia cayennensis, Vismia japurensis, Vismia macrophylla, Vochysia ferruginea, Vochysia aff. tetraphylla, Warszewiczia coccinea, Xylopia calophylla, Xylopia ligustrifolia, Xylopia plowmanii, Xylopia sericophylla, Zanthoxylum fagara and Zygia latifolia.*

## Appendix 1E: Species categorized as medium threat according to IUCN criteria in forests.

*Allophylus amazonicus*, *Bauhinia longicuspis*, *Bauhinia unguolata*, *Bellucia grossularioides*, *Bellucia pentamera*, *Bellucia strigosa*, *Campsiandra angustifolia*, *Casearia aculeata*, *Casearia commersoniana*, *Casearia sylvestris*, *Casearia ulmifolia*, *Casearia zizyphoides*, *Cecropia metensis*, *Cecropia peltata*, *Cecropia sciadophylla*, *Chomelia tenuiflora*, *Clathrotropis brachypetala*, *Clitoria dendrina*, *Clitoria guianensis*, *Clusia amazonica*, *Clusia grandiflora*, *Clusia insignis*, *Cochlospermum orinocense*, *Combretum laxum*, *Cordia alliodora*, *Cordia bicolor*, *Cordia nodosa*, *Cordia panamensis*, *Cordia ucayaliensis*, *Couepia chrysocalyx*, *Coussarea paniculata*, *Crotalaria incana*, *Cynometra marginata*, *Dacryodes chimantensis*, *Deguelia scandens*, *Dendropanax caucanus*, *Desmoncus polyacanthos*, *Dichapetalum spruceanum*, *Eriotheca macrophylla*, *Erythroxylum amazonicum*, *Erythroxylum divaricatum*, *Erythroxylum macrophyllum*, *Eschweilera bracteosa*, *Eschweilera decolorans*, *Eschweilera parviflora*, *Eschweilera parvifolia*, *Eschweilera tenuifolia*, *Pterocarpus dubius*, *Eugenia cribrata*, *Garcinia macrophylla*, *Garcinia madruno*, *Gnetum leyboldii*, *Gnetum nodiflorum*, *Godmania aesculifolia*, *Guatteria ucayalina*, *Gustavia augusta*, *Gustavia hexapetala*, *Herrania nitida*, *Hevea benthamiana*, *Hirtella americana*, *Hirtella bullata*, *Hirtella paniculata*, *Hirtella racemosa*, *Ilex inundata*, *Laetia suaveolens*, *Machaerium biovulatum*, *Machaerium floribundum*, *Machaerium quinata*, *Macrolobium bifolium*, *Macrolobium multijugum*, *Macrosamanea consanguinea*, *Macrosamanea discolor*, *Macrosamanea pubiramea*, *Marsdenia macrophylla*, *Melicoccus bijugatus*, *Miconia dolichorrhyncha*, *Miconia holosericea*, *Miconia minutiflora*, *Miconia tomentosa*, *Miconia trinervia*, *Mouriri myrtilloides*, *Mouriri nigra*, *Ormosia macrophylla*, *Osteophloeum platyspermum*, *Petrea volubilis*, *Phyllanthus attenuatus*, *Phyllanthus elisiae*, *Picramnia magnifolia*, *Plinia involucrata*, *Posoqueria latifolia*, *Pourouma minor*, *Quassia simaruba*, *Rinorea flavescens*, *Rudgea crassiloba*, *Ruprechtia tenuiflora*, *Ryania speciosa*, *Senna silvestris*, *Simaba orinocensis*, *Simira rubescens*, *Siparuna guianensis*, *Sloanea guianensis*, *Stachyarrhena penduliflora*, *Stylogyne turbacensis*, *Swartzia leptopetala*, *Swartzia myrtifolia*, *Tabernaemontana amygdalifolia*, *Tapura guianensis*, *Theobroma subincanum*, *Tovomita spruceana*, *Ruprechtia ramiflora* and *Tacarcuna amanoifolia*.

## Appendix 1F: Species categorized as low threat threat according to IUCN criteria in forests.

*Abuta grandifolia*, *Albizia subdimidiata*, *Alchorneopsis floribunda*, *Alibertia bertierifolia*, *Allophylus racemosus*, *Amaioua guianensis*, *Aparisthmium cordatum*, *Bignonia aequinoctialis*, *Campsiandra nutans*, *Capirona decorticans*, *Casearia hirsuta*, *Casearia javitensis*, *Casearia mollis*, *Cathedra acuminata*, *Chomelia spinosa*, *Miconia tocochoidea*, *Coccoloba lucidula*, *Coccoloba mollis*, *Coccoloba portuguesana*, *Combretum coriifolium*, *Conceveiba guianensis*, *Connarus lambertii*, *Connarus ruber*, *Cordia tetrandra*, *Cordia concolor*, *Cornutia microcalycina*, *Crateva tapia*, *Croton cuneatus*, *Croton orinocensis*, *Cuspidaria sceptrum*, *Cybianthus llanorum*, *Cynometra bauhiniifolia*, *Dalbergia foliosa*, *Dalbergia hygrophila*, *Diospyros poeppigiana*, *Discocarpus gentryi*, *Doliocarpus dentatus*, *Doliocarpus major*, *Doliocarpus multiflorus*, *Olex candida*, *Faramea capillipes*, *Faramea sessilifolia*, *Faramea torquata*, *Forsteronia affinis*, *Guapira pacurero*, *Guapira sipapoana*, *Heisteria acuminata*, *Heisteria duckei*, *Henriettea fissanthera*, *Hirtella subscandens*, *Homalium guianense*, *Isertia haenkeana*, *Lacistema aggregatum*, *Leonia glycyarpa*, *Lindackeria paludosa*, *Macrolobium angustifolium*, *Malouetia grandiflora*, *Malouetia virescens*, *Maprounea guianensis*, *Miconia dispar*, *Miconia elata*, *Miconia stephananthera*, *Mouriri acutiflora*, *Mouriri pauciflora*, *Ouratea brevipedicellata*, *Ouratea castaneifolia*, *Pachira brevipes*, *Pachira paraensis*, *Palicourea crocea*, *Palicourea croceoides*, *Phyllanthus niruri*, *Picramnia antidesma*, *Piper arboreum*, *Potalia resinifera*, *Pourouma tomentosa*, *Palicourea justiciifolia*, *Psychotria lupulina*, *Quararibea ochrocalyx*, *Quiina florida*, *Quiina macrophylla*, *Quiina rhytidopus*, *Randia dioica*, *Richeria grandis*, *Rinorea falcata*, *Rinorea pubiflora*, *Rourea glabra*, *Sacoglottis guianensis*, *Schizocalyx bracteosa*, *Securidaca diversifolia*, *Homalolepis cedron*, *Sloanea eichleri*, *Stachyarrhena duckei*, *Sterculia guapayensis*, *Strychnos brasiliensis*, *Strychnos bredemeyeri*, *Strychnos mitscherlichii*, *Stylogyne longifolia*, *Styrax guyanensis*, *Swartzia pittieri*, *Tabernaemontana amplifolia*, *Tabernaemontana grandiflora*, *Tabernaemontana macrocalyx*, *Tabernaemontana sananho*, *Tabernaemontana siphilitica*, *Tachigali hypoleuca*, *Tachigali plumbea*, *Tapura acreana*, *Miconia tococoronata*, *Urera baccifera*, *Vasivaea alchorneoides* and *Vismia guianensis*.