Tropical Wooded Peatland in Delta Amacuro State, Venezuela

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ABSTRACT

Reconnaissance on edaphological and biological aspects was carried out in a peatland forest near the town of Piacoa in Delta Amacuro State, southeastern Venezuela. Thirteen peat samples were taken in a stratigraphic transect, using Ramsar peat extraction and analysis protocol to study tropical peatlands. Physicochemical parameters were characterized with basic laboratory analysis: color according to the Munsell scale, relative humidity, solubility in water, specific density, pH, conductivity, percentage of organic carbon and percentage of organic matter. Rapid ecological evaluation of vegetation and ichthyofauna associated with aquatic bodies was carried out. Part of a large extension of Orinoco peatlands in delta region, the study area is a marshy wetland which, according to the Ramsar classification, qualifies as forested peatlands (Xp category). Paleoclimatic, palynological and edaphological information in the literature indicates that the peatlands were formed during Holocene processes of marine transgression that occupied settling basins and lowlands where the vegetation was not very different from the current one. Samples collected at different depths (0 to 220cm) clearly show horizons with two color tones: one dark or black (associated with a good surface aeration), and a yellowish brown or brown, associated with an absence or little amount of oxygen as it goes deeper. The pH values decrease with depth (4.25 at the top and 3.9 or 3.5 at depth). The peat has a high water retention that ranges between 60% and 83%. Vegetation in the wetland is diverse: 31 species of plants within 14 families that include tree, shrub and hydrophilic grassland vegetation were identified. In associated water bodies, 41 species of fish grouped within 27 families were found.

Key words: wetlands, peatlands, peat, turbal, Orinoco Delta, climate change, carbon trap

RESUMEN

Se realizó un reconocimiento sobre aspectos edafológicos y biológicos en una turbera o turbal cercano a la población de Piacoa en el estado Delta Amacuro, sureste de Venezuela. Se tomaron trece muestras de turba en transectos estratigráficos, utilizando el protocolo de análisis y extracción de turba de Ramsar para estudiar turberas tropicales. Fueron caracterizados parámetros fisicoquímicos con análisis básicos de laboratorio: color según la escala de Munsell, humedad relativa, solubilidad en agua, densidad específica, pH, conductividad, porcentaje de carbono orgánico y porcentaje de materia orgánica. Se realizó una evaluación ecológica rápida de la vegetación y la ictiofauna asociada a los cuerpos acuáticos. La turbera donde se trabajó forma parte de una gran extensión de turberas del Orinoco en la región del delta. El lugar es un humedal pantanoso que, según la clasificación Ramsar, califica dentro de la categoría Xp (turba arbolada). La información paleoclimática, palinológica y edafológica en la literatura indica que éstas se formaron durante procesos de transgresión marina del Holoceno antiguo que ocuparon cubetas y tierras bajas donde existía una vegetación no muy diferente a la actual. En muestras recolectadas a diferentes profundidades, se pueden ver claramente horizontes con dos tonos de color: uno oscuro o negro (asociado a una buena aireación superficial), y otro marrón, pardo o amarillento, asociado a ausencia o poca cantidad de oxígeno a medida que se profundiza. Los valores de pH disminuyen con la profundidad (4,25 en la parte superior y 3,9 o 3,5 en profundidad). La turba tiene una alta retención de agua que oscila entre el 60% y el 83%. La vegetación en el humedal es diversa, habiéndose identificado 31 especies de plantas dentro de 14 familias que incluyen vegetación de árboles, arbustos y pastizales hidrofílicos. En cuerpos de agua asociados se identificaron 41 especies de peces agrupadas en 27 familias.

Palabras Clave: Humedales, Turbera, Turbal, Turba, Delta del Orinoco, Cambio climático, Trampa de carbono

INTRODUCTION

Peatlands (or turbales) are environments characterized by the progressive production and accumulation of organic matter called peat. Peat is made up of semi-decomposed plant remains in environments with permanent water saturation, low oxygen levels and high acidity. In these environments, plant matter have been accumulating for thousands of years because their rate of accumulation exceeds the rate of decomposition. The natural vegetation of tropical peatlands can include dicotyledons, palms, mangroves, sedges, grasses, mosses, and other plants. The diversity of vegetation produces peat with different structures, which can include wood, herbaceous rhizomes, and roots. In highly decomposed peat ("muck"), plant remains are less recognizable and highly decomposed, and are very dark in color (Ramsar 2018).

In Venezuela most studies on peatlands have focused on the high Andes (e.g., Molinillo and Monasterio 2005). In contrast, peatland in Piacoa (Venezuela) located in the Imataca Mountain Range is an extension of lowland peatlands and is estimated at 70,000 hectares according to

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Table 1. Events relevant to the evolution of the Orinoco River and the delta during the Holocene.

Sub-epoch	Numerical age (years ago)	Climatological, biological and others events relevant to the evolution of the Orinoco River and the delta during the Holocene
Upper Late Holocene	4,200	• Significant quantities of Amazonian sediments are transported to the Orinoco delta platform, continuing coastal progradation there (Warne et al. 2002)
Middle Holocene	8,200	• Sea level approached its present stand. The stabilization of the sea-level that occurred would have favored the transgression of the coastal line (Montoya et al. 2009) • The sediments transported by the Orinoco were not distributed uniformly breaking the natural channels, changing their course (avulsion) and forming now the main channels (Aslan et al. 2003)
	9,000	• Worldwide the rise in sea level brought with it a strong saline intrusion around coastal lands contributed to the annihilation of large tracts of forests and in other salt-intolerant vegetation. The massive amount of dry plant material from these destroyed phytocommunities are now part of the accumulated peat (Hapsari et al. 2017). • Humid climate like the one now experienced (Schubert 1988; Villagrán 1993; Latrubesse 2003). The bulk of the vegetation that formed the Orinoco peat is not very different from what we see today Montoya et al. 2009; Leal and Bilbao 2011 and Ballesteros et al. 2014)
Lower Early Holocene	11,700	• Worldwide, most of today's tropical continental peatlands began forming, relatively close to the coastal ranges (around 10,000 years ago) (UO 2020). • Great fluvial channels of the Venezuelan llanos rivers were created and a period of sediment deposition occurred. During this time the bulk of the material came to shape the landscape, including peat (plant material trapped in situ in depressions in the vicinity of the river). Waters from Andean rivers (including Colombian territory), and Guiana rivers, carried sediments downstream to form the Orinoco Basin (Méndez-Baamonde 2005 a and b). • Final glaciation Wisconsin (Last Glacial Maximum, LGM) The melting of the ice begins slowly, and the transgression begins as the sea advances over the continent (Vivas 2011)
	1,6M to 10,000	• Glaciation Wisconsin. • 1,4 million years ago the waters of the sea were withdrawn from the coasts because its level was 110 meters below its current height (regression). The sediments carried by the ancient Orinoco were discharged directly from the continental shelf to the deep sedimentary environments of the Atlantic Ocean.

Matos (2014). This area has historically alternated between being densely covered with vegetation in humid periods, and more open during dry periods in sync with climate changes during recent geological times (Schubert 1986; González et al. 2013). Establishment of peat on the floodplains of Orinoco took place in many depressions during favorable times for the accumulation of organic matter, aided by global changes in sea level occurred in Holocene. Although the Orinoco Delta rests on very old deep rocky strata, it contains superficial sedimentary facies that constitute Venezuela's youngest lands, mainly Holocene deposits (González de Juana et al. 1980; Vivas 2011 and Latrubesse 2003) and that is why the peat is said to of recent origin. Below, in the Table 1 we summarize the main events that were relevant in the formation of the Orinoco delta and the Piacoa peatlands.

Peatlands are vulnerable at various levels, either to anthropogenic interventions (burning, use of peat carbon and drainage of their waters; Cole et al. 2022) or large-scale environmental changes, either natural or induced, for example, climate change effects (Garcin et al. 2022). These authors point out that tropical peatlands in the Congo (Africa) have responded intermittently to environmental changes by reversing carbon accumulation-loss-accumulation pattern, depending on whether the climate was predominantly humid or dry. In this regard, they say: "drying climate probably resulted in a regional drop in the water table, which triggered peat decomposition, including the loss of peat carbon accumulated prior to the onset of the drier conditions". Therefore, from the point of view of carbon accumulation, the environmentally beneficial service provided by peatlands, because for millennia they have

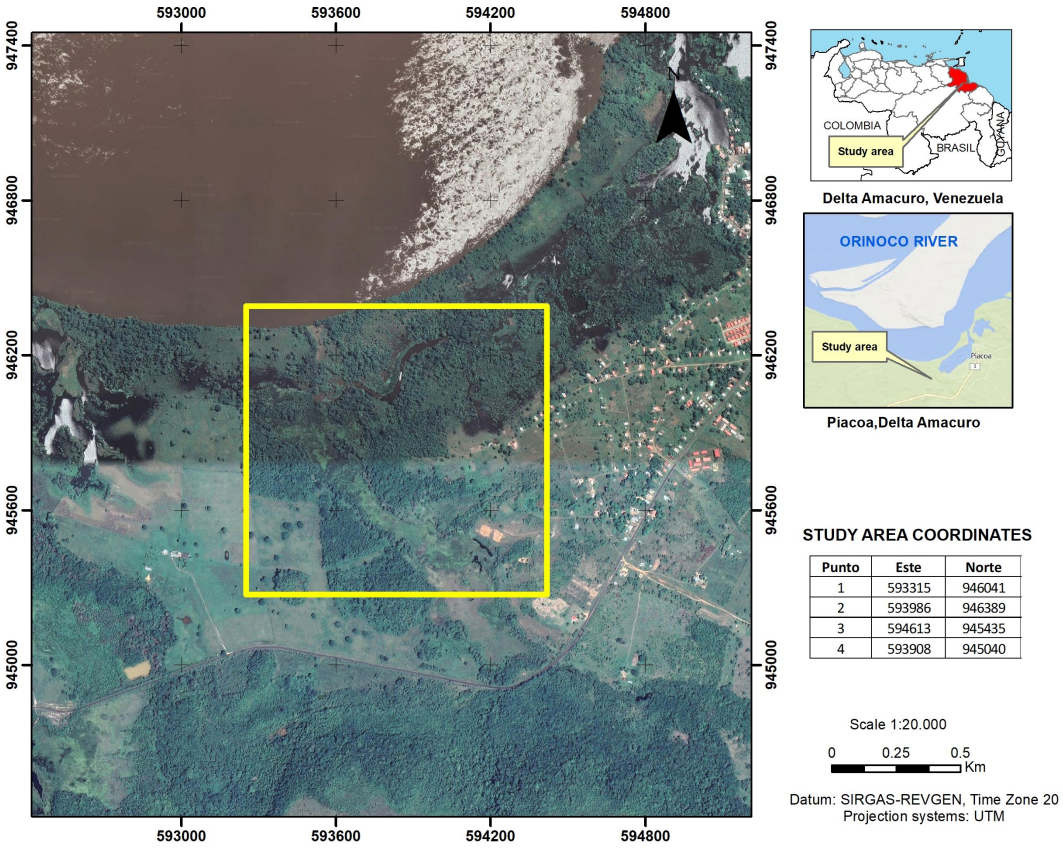

Figure 1. Location of study area. (Produced by José Gregorio Quintero)

been trapping CO2, which is one of the strongest promoters of the greenhouse effect (and collaterally of global warming), may be compromised in the long term depending on how global and local climate change scenarios evolve.

In Venezuela, if the long-term precipitation decrease data were confirmed, as Olivares (2018) points out (values with downward trends consistent with 2008 reports by other authors), this will eventually mean a very dry environment. In this scenario, as hypothesized by Garcin et al. (2022) for peatlands in the Congo, peatlands here in the Orinoco would lose accumulated carbon. If, on the contrary, as pointed out by Sachs et al. (2009) the Intertropical Convergence Zone (ICZ) will continue its migration to the north, reaching 126 kilometers north of its current position at the end of the century, this could affect the country by promoting an increase in the intensity, volume and frequency of rainfall, as well as the rainy coverage area. This could mean a more humid climate, which would indirectly favor the accumulation of carbon.

METHODS

Peat Analysis

Thirteen soil samples with peat were taken. Ramsar peat extraction and analysis protocol and studies of tropical peatlands were employed (Marrero 2017; Ramsar 2018). Samples were collected in a stratigraphic transect with two or three samples per point (50 cm, 100 cm and 220 cm), both in the soil and in the peat within the floodable grassland. All the samples were placed in 2 kg plastic bags and labeled for later analysis in soil laboratories, where were determined the following parameters: color according to the Munsell scale, relative humidity, solubility in water, specific density, pH, conductivity, percentage of organic carbon and percentage of organic matter.

Collections and Identification of Botanical Specimens

An in situ species recognition was carried out, with botanical specimens collected for their exhaustive identification in the UNELLEZ PORT University Herbarium. The analysis was complemented with phenological data available at the time of collection. The distribution of vascular species was consulted in the New Catalog of the Vascular Flora of Venezuela (Hokche et al. 2008), the Trópicos database (2022) and JSTOR Global Plants (2022).

Record for Aquatic Fauna (Fish)

Fish specimens were collected with nets, photographed, and after identification they were released. Local fish centers were visited in the Piacoa market, where people were interviewed about the origin of the fish.

Study Area and Characteristics

The Orinoco delta region is a very complex environment both in its genesis and in its current maintenance (Méndez-Baamonde 2005a, b). It is divided into four large natural re-

gions: 1) the northeastern swampy plain, 2) the deltaic plain of the Morichal Largo and Tigre rivers, 3) the Delta itself, and 4) the deltaic plains south of the Río Grande (Méndez-Baamonde 2005a, b; González 2011; Colonnello 2014; Marrero and Rodríguez-Olarte 2017). The southeast sector is dominated by the Rio Grande (the principal distributary) and complex networks of anastomosing fluvial and tidal channels. The abundance of siliciclastic deposits suggests that fluvial processes such as overbank flooding strongly influence this area (Aslan et al. 2003).

The area examined where peat is located is an extension of the lower delta, and to a lesser extent, of the Middle delta. It is a plain under the marine and fluvial action of the Rio Grande and the rivers that drain from the north of the Guiana Shield, such as the Imataca, Acure, and Arature, whose sediments originate fluvio-marine reliefs, such as: channels (in the process of silting), plains flat surface swamps and in positions below sea level, marshes or swampy areas, banks and estuary islands. All of these landforms, with slopes between 0 and 1% (Castillo 1994; González 2011) have poor drainage.

Points where samples were taken are within a peat whose estimated area is 5500.4 hectares; is located near the town of Piacoa, in Juan Bautista Arismendi, Casacoima Municipality in the Delta Amacuro State and Northwest of the National Imataca Forest Reserve. Piacoa´s peats have been well studied, among others, by Matos (2014), who carried out a survey with a view to evaluating the area for its peat production potential (i.e., for use as an agricultural substrate). These peats are a natural resource located within the boundaries of the Imataca Forest Reserve and under the management and administration of the Ministerio del Poder

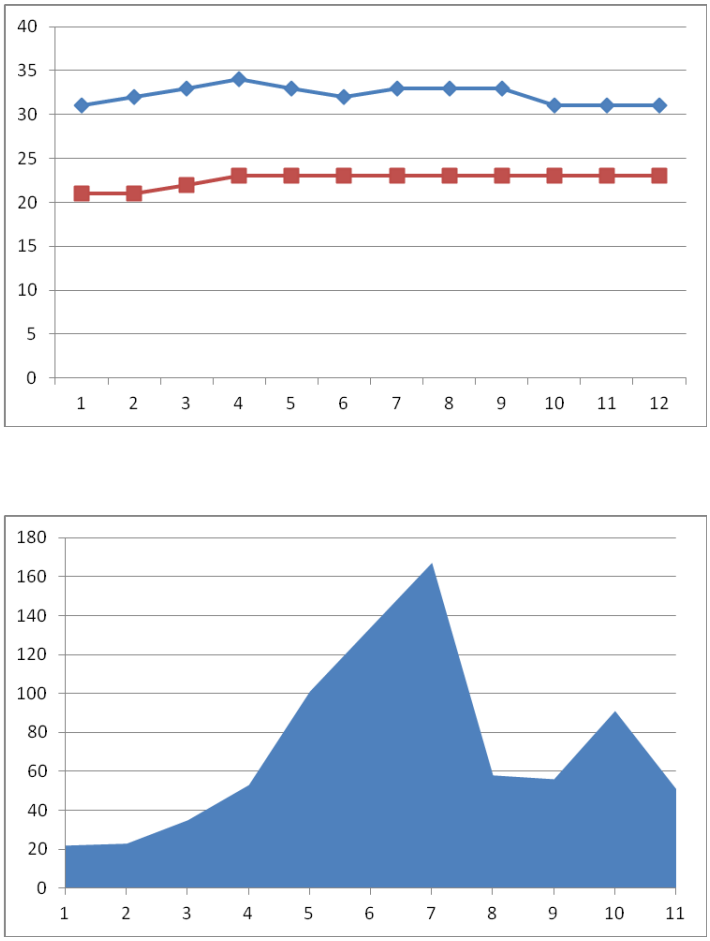

Figure 2. Variations in temperature and precipitation in Tucupita, Amacuro Delta State. (Produced by José Gregorio Quintero)

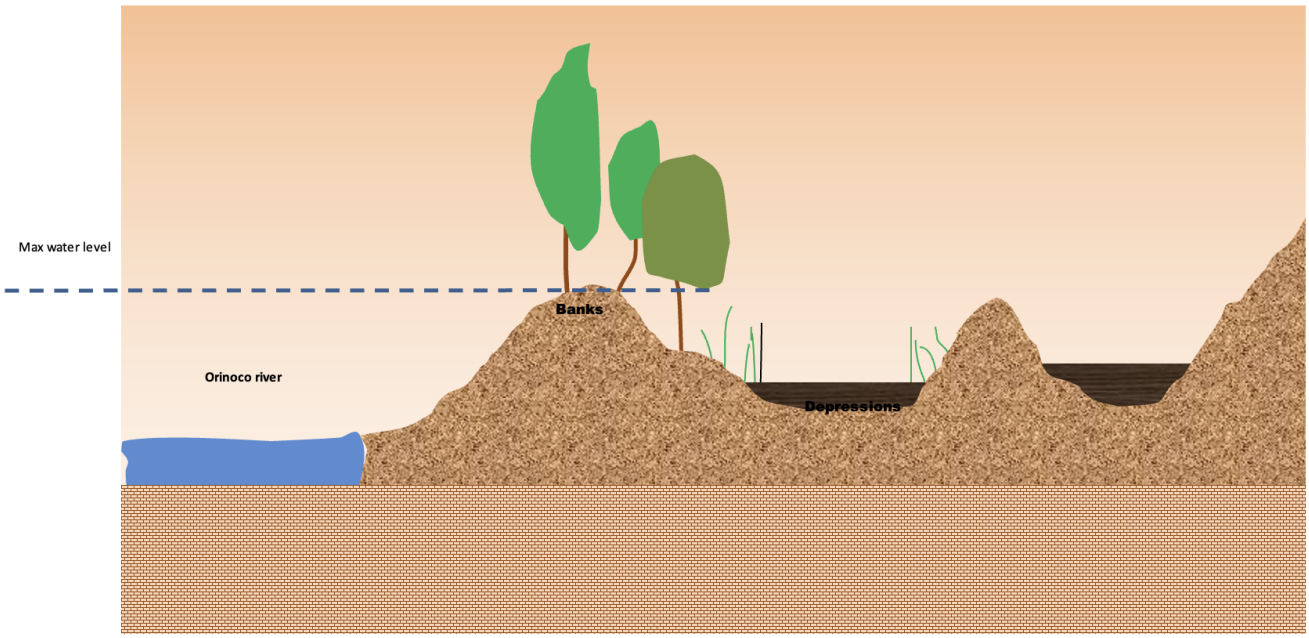

Figure 3. Schematic relief of the area where samples were taken in the Piacoa peatland, highlighting the basins or depressions of accumulation. (Produced by Críspulo Marrero)

Figure 4. On the left, general views and details on places where the samples were taken in the Piacoa peat, which corresponds to the Xp type of the Ramsar classification: peat-filled settling basin dominated by grasslands and/or floodplain forests. On the right, detail of one of the soil-peat profiles taken at the work site at different depths. (Photos by Críspulo Marrero, February 2022)

Popular del Ecosocialismo (MINEC).

Climate. Annual average temperatures range between 21ºC and 31ºC. Average annual rainfall varies between 1260 mm and 1,400 mm (Figure 2). The annual precipitation regime tends to be bimodal, registering maximum values in June, July, and August, to later decrease in September and increase again from October to December. The dry season occurs from February to April, with May being a transitional month (Comerma and Mogollón 1994; Rondón-León 2009). The relative humidity values are high: in July with 85.5% and in December 81.5% - the months of maximum humidity. These high values are a consequence of the high rainfall, high evaporation (1800 mm) and the presence of woody vegetation that allows the concentration of humidity. The prevailing winds in the delta are the trade winds from the northeast, which freely run through the delta plain until they meet the foothills of the Imataca mountain range south of the Rio Grande.

Relief. The average elevation does not exceed 10 meters above sea level. There is a system of depressions whose slopes are very low (less than 0.5%), while the dragging of sediments from the Orinoco has formed banks of riverbanks, creating a system of sedimentation basins where water is retained (Figure 3). As mentioned, historically the area is a means of recent sedimentary accumulation (Holocene) active at least since the last marine transgression, when the sea advanced over the continent. This rise in sea level facilitated the filling of basins with marine clays, which were locally mixed with peat and fluvial sediments, especially in the upper delta, where the influence of the Orinoco River is greater. Periodic flooding of the Orinoco River, excess rainwater, and the slow drainage of micro-basins produce conditions of total or partial water saturation favoring peat formation across almost all of the area.

Table 2. Basic physicochemical parameters at different depths in the Piacoa peat. (Produced by Críspulo Marrero)

Depth (cm)	0-40	40-150	150-220
Color Munsell	Black or dark 10YR2/1)	Brown or yellowish dark or brown (10YR 4/4)	Dark yellowish or brown (YR 4/4)
Humidity (%)	52	64	76
Specific density (g/cm3)	0.79	0.74	0.71
Solubility in water (mg/l)	83	75	60
pH	4.25	4.13	3.94
Conductivity (ɥS/cm)	168	155	180
Organic carbon (%)	39.5	29.53	28.4
Organic material (%)	68	50.35	49

RESULTS

Peatland Type

According to Ramsar classification, the Piacoa´s peatlands can be considered within the forested peatlands or peat-swamp forests (Xp category). Characteristically, they are peat colonized by trees, shrubs, or grassland vegetation. This category includes oxbows (meanders or dead arms of the river) full of peat and sedimentation basin dominated by flooded grasslands (Figure 4). Also included in this category are the peaty flooded forests, which cover extensive lowlands and are found in large areas in the western Amazon basin and on the northeastern coast of South America (Venezuela, Guyana, Suriname, and French Guiana).

Basic Physicochemical Evaluation of Piacoa Peat

The results of the physicochemical analysis are presented in Table 2. There are two color tones of peat: one dark or black and the other yellowish brown or brown. The difference in color is associated with aeration or oxygenation processes: in the case of dark peat (highly decomposed organic matter) there was extensive contact with oxygen while for brown peat it was limited (fiber were still visible). The pH values decrease as you go deeper: 4.25 at the top and 3.9 or 3.5 at the deepest part. Water retention is high (60% to 83%). The bulk density of the material varies once it has dried: it goes from 0.25 ton/m3 at the time of extraction to 0.65-0.75 once dried. This is a consequence of the arrangement of the dry particles, which are compacted when they lose moisture. The percentages of organic matter vary between 68% for peat near the surface to 49% for deep peat. This indicates an incipient lignification process of the peat at depth.

Vegetation and Flora of Piacoa Peatland

The area's vegetation dominated by grasslands dedicated to cattle ranching interspersed with relicts of humid forest as well as thickets in different degrees of succession (Figure 5). Figure 6 shows some of the flora species found. Orinoco River is the main shaper of the landscape, permanently contributing to water balance in the main estuaries of the region. Four vegetation units were defined within and around the peat: Floodable Grassland (in the peat area), Savannah, Shrub Land (Matorrales), and Low Forest. Below is a description, as well as details of main elements that make up each defined unit.

Floodable Grassland. This unit contains water almost year-round, so its dominant species were aquatic herbs with 31 species reported. Dominant families were: Poaceae, Cyperaceae, Lentibulariaceae and Onagraceae. It was common to observe *Montrichardia arborescens* forming dense colonies, as well as dense colonies of several Poaceae species (*Hymenachneam plexicaulis, Paspalum virgatum, Andropogon bicornis*, among others). Bora (Eichhornia azurea) was also well established forming large monotypic colonies. Among grasses and on the banks of the estuary, it was common to observe at least three species of carnivorous plants of the genus Utricularia. Floating plants, among them were the aquatic ferns *Azolla filiculoides* and *Salvinia auriculata*.

Savannah. Predominant savannahs in the Piacoa sector are of anthropogenic origin. In this case they are open and wooded, where the woody element is very scarce. In other cases the trees were introduced species such as Mango (*Mangifera indica*) and Pesgua (*Syzygium cumini*) that have become invasive species, expanding through natural areas. In the floristic inventory, 23 native species and two

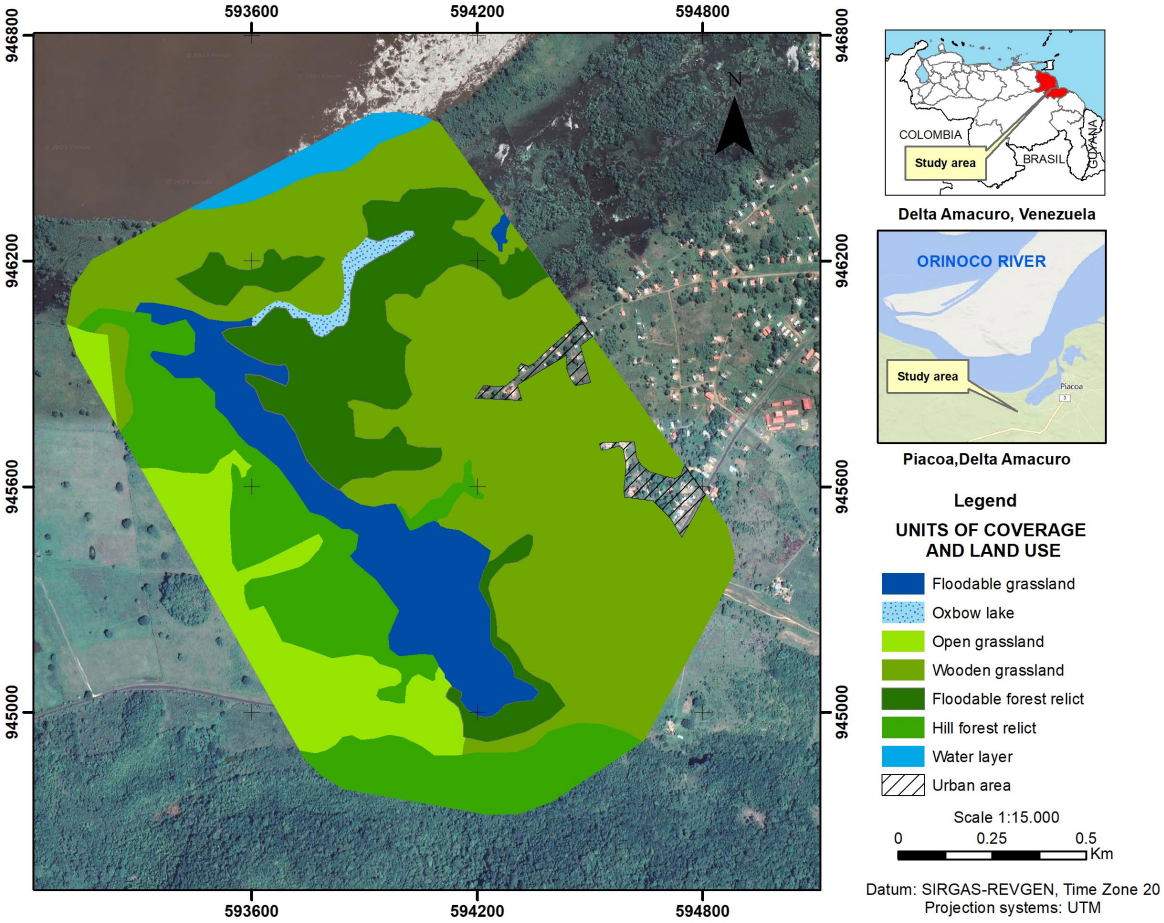

Figure 5. Map of vegetation cover and land use in the Piacoa peatland area, Delta Amacuro. (Produced by José Gregorio Quintero)

introduced species were found, with the dominant families being Cyperaceae and Poaceae. The herbaceous matrix was composed of Trachypogon spicatus, Axonopus anceps, Panicum rudgei, Bulbostylis junciformis, Lagenocarpus rigidus, Rhynchospora albomarginata, Polygala timotou, and Peramaga lioides. The woody elements were scattered and were made up of *Byrsonim acrassifolia*, *Curatella americana, Mabeataquari, Xylopia aromatica*, and *Miconia albicans*. *Securidaca marginat*a and *Sabicea velutina* were among the suffrutes observed, while lianas were represented by *Mandevilla leptophylla, Davilla kunthii* and *Passiflora laurifolia*.

Matorrales. Due to the livestock activity in the area, the formation of thickets in different successional stages is frequent. The floristic inventory recorded 60 species with dominance of Poaceae, Leguminosae, Cyperaceae, Melastomataceae, Rubiaceae, Asteraceae and Solanaceae. The most common species were *Pityrogramma calomelanos, Achyranthes asperavar pubescens, Bidenscy napifolia, Cyperus luzulae, Fimbristy lismiliacea, Fuire naumbellata, Kyllingaodorata, Coutoubea ramosa, Ludwigia hyssopifolia, L. talifolia, Phytola ccarivinoides, Andropogon virgatus*, and *Paspalum virggatum*. Woody species such as *Trema micrantha, Bixauru curana, Senna multijuga, Vismia laxiflora, Clidemia bullosa* and *Miconia serrulata* were found in the sites that have not been buried by the tails. The most common vines and lianas are *Clitoria arborescens, Momordica charantia, Stygmaphyllon sinuatum, Gouania polygama* and *Cissuserosa species*.

Low Forest. These forests are heavily impacted by logging, sporadic burning and expansion of the livestock frontier. Differences can be evidenced between forests in hilly systems and those subject to flooding. A total of 30 species were reported, with the following families being most abundant Rubiaceae, Chrysobalanaceae, Heliconiaceae, Leguminosae, and Arecaceae. They had medium to sparse coverage, with one or two tree strata, made up of individuals from 6 to 18 m tall, including *Perocarpus acapulcensis, Matayba peruviana, Protium* sp., *Ouratea ferruginea, Hirtella racemosa, Licania* sp., *Aldina castanea, Brownea coccinea* and *Licania* species.

The Area's Importance on Local Fishes

The Orinoco delta area is very rich in wetlands, both marine and freshwater. Sediment transport processes and deltaic formation have produced many channels that communicate in a complex way, and everything is highly interconnected. The amount of fluvial sediments and organic matter present are a source of food for a multitude of organisms, especially fish. Lasso and Sánchez-Duarte (2011) recorded 440 species comprised of 20 orders and 82 families

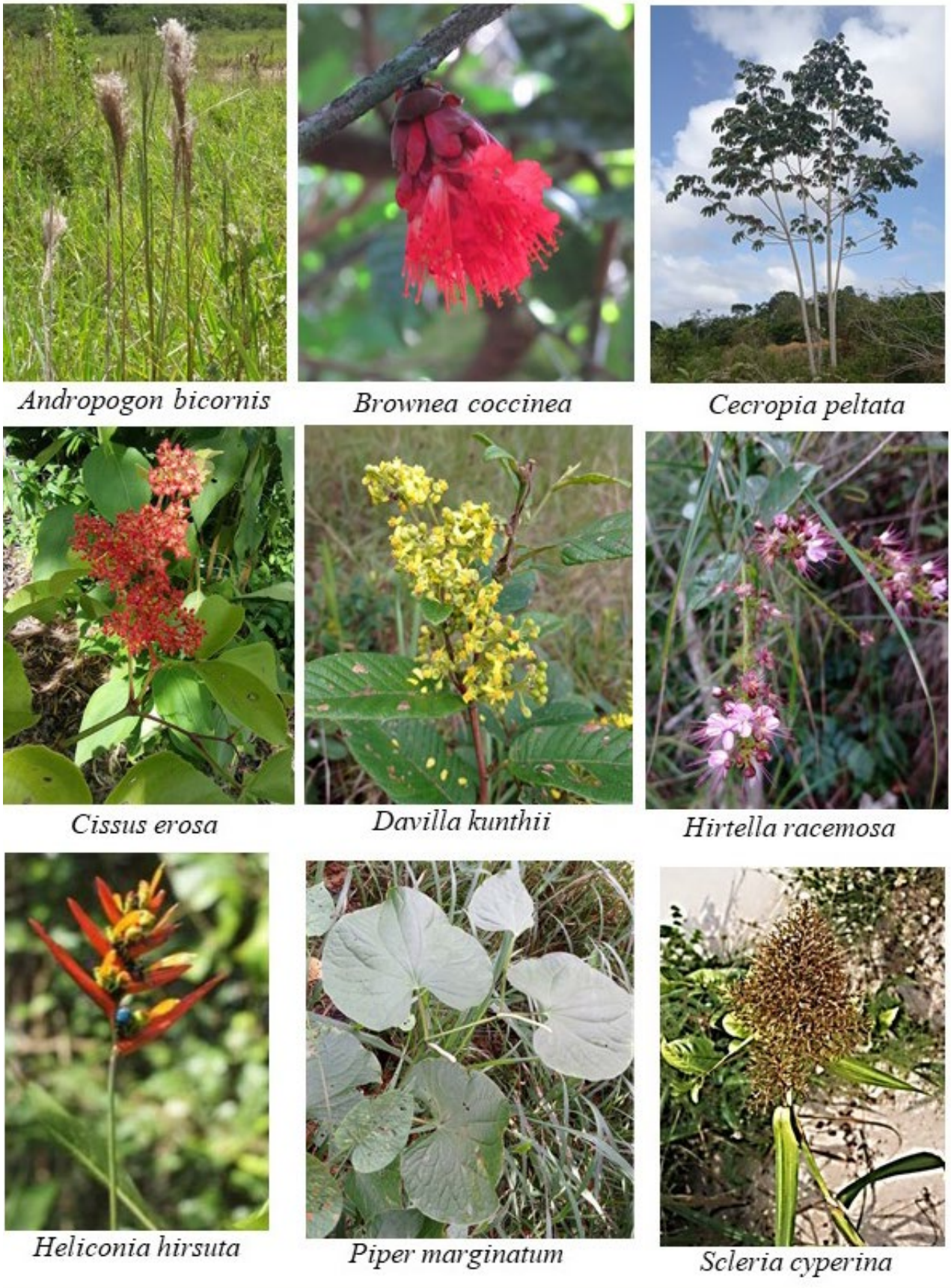

Figure 6. Common species in the Piacoa peatland area, Delta Amacuro. (Photos by Miguel Niño and Daniela Canelón, February 2022)

in the Orinoco River delta. The best represented groups were the orders Characiformes, Perciformes (e.g., curvinas, mackerel, and mullet) and Siluriformes (catfish) with 132, 101 and 87 species, respectively. The five families with the highest species richness included Characidae (73 species), Cichlidae (26 species), Pimelodidae (24 species), Sciaenidae (23 species), and Loricariidae (17 species). Of the species identified for this system, 39% have marine and estuarine habits, while the rest are strictly freshwater.

These same authors claimed that the delta zone and particularly the "bars" and the mouths of numerous streams of the Delta, represented areas of great productivity and ecological and fishing importance. In some areas, periodic evaluations of fishing activities have been carried out, which have yielded figures of around 6,000 tons/year of commercial fishes. For this reason, the entire Orinoco delta is essential for the reproduction of numerous migratory aquatic species of fish and crustaceans, both those coming from fresh water (rest of the basin) and those coming from the oceanic side. They also constitute a refuge and feeding area for all the larval and juvenile forms of the aforementioned organisms.

The aquatic system which forms Piacoa peat is connected with other Orinoco delta environments, and despite not being a permanent water body is home to many species of the local ichthyofauna. In many places there is a layer of surface vegetation above the water, leaving enough space under it for the movement of aquatic life between the riverbed and the flood zone once they are connected. For this reason, this system is very dynamic and periodically renewed with the entry of water from the Orinoco River.

This process of movement and those places of shelter for fish are vital to the area, because a lot of fish from the river is consumed there, as can be seen on a visit to the local market. Figure 7 shows the local fish species (a total of 41 species in 27 families are reported) and 6 commercially important species captured in the area, which were photographed at the Piacoa's Saturday market, on the banks of the Orinoco. Among the latter are: Pseudoplatystoma, Ageneiosus, Erithrinus, Hoplosternum, and Mylossoma.

FINAL CONSIDERATIONS

The Orinoco peatlands are part of the wetland complex in the megadelta of this river. Here, in this portion of the Venezuelan territory, we clearly see that there is a connecting link between past climatic events (accumulation of organic matter in the Holocene), a rich biodiversity in the present, and a valuable resource (i.e., organic fertilizer) that can improve farmland to provide food now and in the future. For these reasons, it is necessary to study the peatlands and their relationship to maintain and support a healthy aquatic system to preserve what is essential to the current aquatic ecosystem and exploit what can be done within pertinent guidelines that regulate the use of these valuable resources in a sustainable manner.

Tropical peatlands are one of Earth's most efficient natural carbon stores. Specifically in the Orinoco delta, Vegas-Vielarrubia et al. (2010) estimate that first centimeters of the soils store 45.0–97.0 kg m− 2. Consequently, the Orinoco delta contributes approximately 0.049 Gt to the global carbon storage. This fact, in relation to peat lands in general, gives rise to an international concern as they experience rising threat from deforestation and drainage (Cole et al. 2022). Methods of peat extraction must be applied in accordance with the country's commitments to climate change mitigation.

This entire area is an environment in a continuous process of expansion and evolution, due to the incessant supply of sediments transported by the Orinoco River and the area's tributaries. Likewise, the annual flood patterns imposed by the water regimes mean that the ecosystem is not static, but on the contrary very dynamic and constantly changing. This means that a large number of animals and plants species take refuge in the place. There are elements of fauna and flora there that must be studied in order to systematically quantify the immense biodiversity present.

ACKNOWLEDGMENTS

We'd like to acknowledge and thank José Gregorio Quintero who prepared maps and the figure on climatic data.

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Pyrrhulina sp

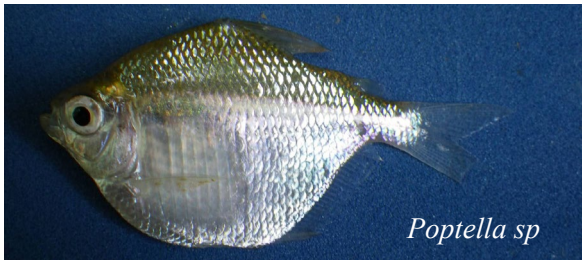
Gymnotus carapo

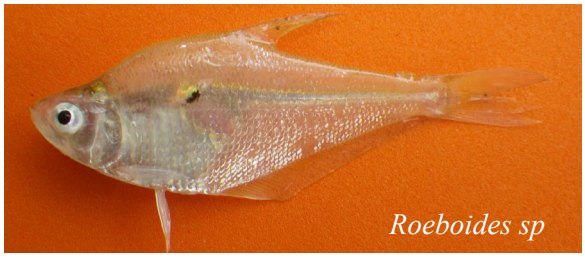
Hoplias malabaricus

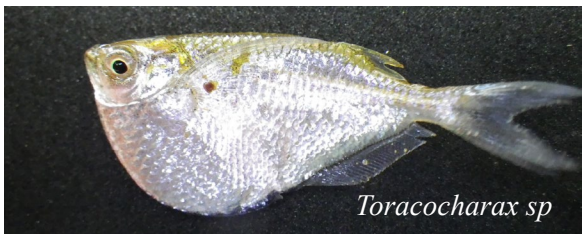
Eigenmannia virescens

Sternopygus macrurus

Ageneiosus sp







Trachelyopterus galeatus

Fish for sale at the Piacoa flea market

Figure 7. Some fish species observed in the area of the Piacoa peatland. (Photos by Críspulo Marrero)

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