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Biodiversity and Conservation of the Estuarine and Marine Ecosystems of the Venezuelan Orinoco Delta

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1. Introduction

1.1 Oceanographic features and eco-regions of the Orinoco Delta

The Orinoco is one of the largest rivers in South America (2,150 Km). Globally, it is the third in water flow (yearly average of 39,000m^3/s), and the fifth in sediment transportation (150 million tons/year). The Orinoco basin extends for nearly a million square kilometers within Colombian and Venezuelan territories, and is characterized by at least ten large terrestrial and aquatic eco-regions including its opening into the Atlantic through the vast Orinoco Delta (located between 07° 46´ to 10° 00´ N, and 59° 50´ to 62° 35´ W) (Michelangeli, 2000; Bone et al., 2004; Lasso et al., 2010). These deltaic plains were formed by the combined action of sediment and freshwater discharges from the Orinoco, with the tides on a flat alluvial plain (Miloslavich et al., 2011) creating a dynamic ecosystem of fluvial and estuarine habitats. The boundaries between these two habitats are defined according to their altitude above sea level and tidal influence (Lasso & Sánchez-Duarte, 2011), with the fluvial delta corresponding to the mid and high delta according to Cervigón (1985). The lower limit of the fluvial delta varies due to seasonal annual fluctuations in freshwater discharge from the Orinoco, related to regional and, even local, precipitation regimes, and a salt wedge from the sea that moves inward with the incoming tide. In the estuarine delta, the ecological boundary of the fluvial delta is the limit at which the sea water influences the main stream and its channels, while the ecological boundary with the sea is a fringe, which is variable in size and forms after sand or mud bars at the opening of the seaward channels. Along this longitudinal zone from the upper to the lower delta, a geomorphological, physico-chemical, and therefore, biological gradient can be observed. In addition to this longitudinal gradient, a very important transversal gradient also exists, that creates particular lentic ecosystems with specialized biota. Within the Atlantic, the major areas of influence of the Orinoco are (1) the Gulf of Paria, a semi-enclosed area between the Araya Peninsula (Venezuela) and the

west coast of Trinidad, connected to the Caribbean by Boca del Dragón, a ~8km strait, (2) the Orinoco Deltana Platform, the area within the Atlantic Ocean directly adjacent to the Orinoco deltaic plain, and (3) Boca de Serpiente, which connects the Deltana Platform with the Gulf of Paria. These combined areas cover 27,630 km^2 and shelter one of the major and best-preserved wetlands in South America (Figure 1).

In general, the Orinoco Delta and the marine area under its influence has a mean annual temperature between 25 and 28 ^{o}C (range: 15.7 to 37.2 ^{o}C), with two warm peaks, one occurring in May and the other in September. There are two seasons, the dry season occurs between January and April, and the rainy season between June and November. May and December are transitions months between the seasons. The rainy season occurs when the Intertropical Convergence Zone (ITCZ) moves from the Equator towards the Caribbean producing a mean of 1,500 to 2,000 mm of rainfall per year. At this time, winds usually come from the east at an average speed of 3.2 m/s. When the ITCZ moves back to the Equator, the area is influenced by the trade winds that blow from the north-northeast at an average speed of 6.2 m/s (Bone et al., 2004; Martín & Bone, 2007). The area is also affected by the discharge of the Orinoco, which introduces significant changes in salinity, temperature, nutrients, and water quality at both spatial and temporal levels. The productivity of this area is significant and one of the highest in comparison to the eastern Caribbean region. Such high productivity is due to the seasonal upwelling off the northeast coast of Venezuela, and the seasonal dispersal of the Orinoco plume, which covers an area of more than 300,000 km^2 in the adjacent Caribbean and provides for a significant increase in concentration of nutrients and photosynthetic pigments (Martín & Bone, 2007; Muller-Karger et al., 1989). The region is also influenced by the Guiana current, which flows parallel to the coastline towards the northwest (~106m^3/s). The Guiana current originates from the Brazilian current and forms high-energy whirlpool structures that may surpass in intensity the normal circulation and consequently cause transitory episodes of current reversal. The Amazon river also affects this area during the first six months of the year, when its waters extend to the northwest, increasing turbidity in coastal waters, and creating a large plume and sections of brackish water offshore. Tides are very important at the local level particularly because of associated currents. Tides in this region are mostly semidiurnal, but in the Gulf of Paria, tides are mixed. Within the Gulf, the height of the tide is magnified within an increasing gradient from Boca del Dragón to the south, reaching up to 2 m (Martín & Bone, 2007).

Based on ecological and biological features, and aiming toward a better conservation strategy, the area was classified into seven subregions (Figure 1), defined according to the internal variability of their ecosystems, communities, and populations, including those of the terrestrial areas when these are included in the landscape (Klein & Cárdenas, 2009). The subregions, along with the main marine or estuarine features that characterize them, are:

Subregion 1: Paria Peninsula. This zone is characterized by a high landscape heterogeneity, with beaches, coves, a few rocky shores, and wetlands (Mata Redonda and Bajo Alcatraz).

Subregion 2: Sac of the Gulf of Paria. This is a shallow water zone with a depth of 0-15 m characterized by extensive and tall mangrove formations that comprise a heterogeneous wetland with interconnected small channels into which the salt water penetrates. In this region, two estuarine systems (Caño Ajíes and Caño San Juan) are important fish reservoirs, with high biomass of fish larvae of the families Sciaenidae and Lutjanidae.

Subregion 3: Pedernales. This is a shallow water zone with a depth of 0-15 m with important extensions covered by mangroves, and some beaches characterized by boulders. The region has a high abundance of commercial species of fish and crustaceans and it is an important fish reservoir of juvenile stages.
Subregion 4: Gulf of Paria. This zone between 15 m of depth and the limit of international waters serves as an important migratory route for sea mammals, turtles and birds, and as a feeding area for turtles. The area was under intense pressure from trawling fisheries for many years, which were stopped in 2009 with the passage of a new environmental law in Venezuela that mandated that intensive trawling activities cease. While trawling fisheries still take place, they are conducted at the same intensity as artisanal fisheries.
Subregion 5: Boca de Serpiente. This zone with a depth between 0 and 60 m has a complex hydrodynamic system due to the acceleration of marine currents. It is an important migratory route for sea mammals, turtles and birds. Its marine and estuarine biodiversity is relatively high, with high abundance of phytoplankton and zooplankton, including fish larvae. The area contains wetlands with a high biodiversity of birds and a continuous, extensive, tall mangrove formation. Its beaches are formed by muddy sediments and its benthic community shows marked seasonal variations.
Subregion 6: Boca Grande. At a depth between 0 and 60 m, this zone is under the direct influence of the discharge of many of the delta channels, including the largest or Rio Grande. The zone contains numerous islands of different sizes with fragmented mangrove formations. Erosion and sedimentation processes are very active, and the area is significantly influenced by freshwater input. Biodiversity associated with this area is mainly euryhaline.

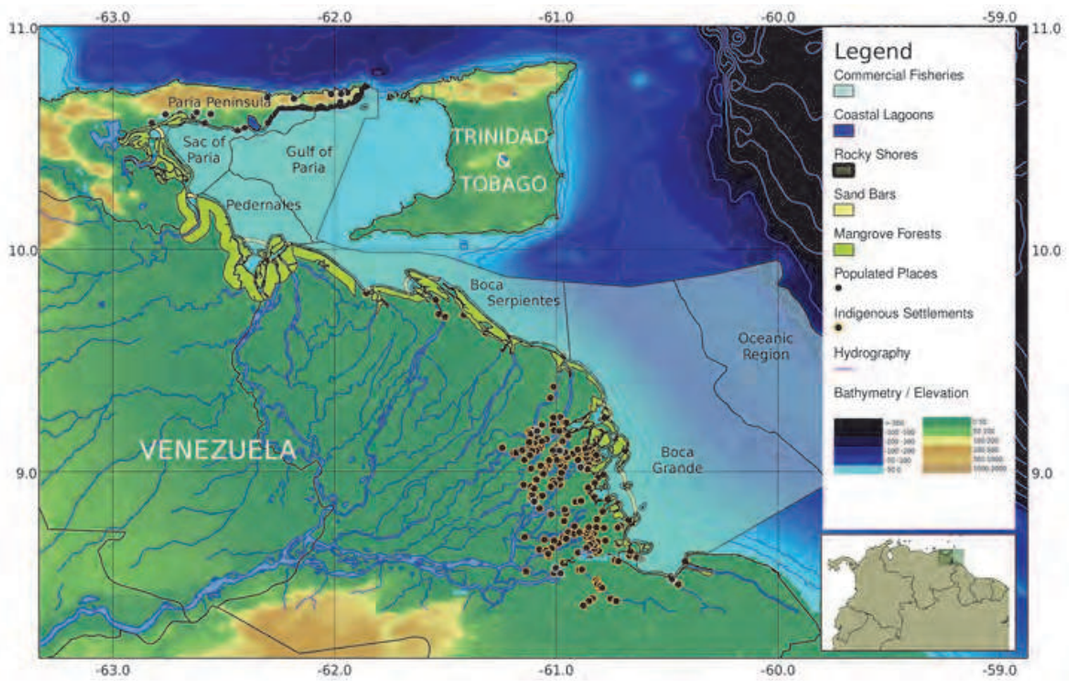

Fig. 1. Map of the Orinoco Delta and Gulf of Paria region in the Venezuelan Atlantic front. Map shows the main ecosystems and human settlements. Bathymetry and elevation scales in meters.

Subregion 7: Oceanic region. Extending from the 60 m isobar to the limit of the Venezuelan border with international waters, this zone is characterized by mostly oceanic species, with low benthic abundance. The area is within important migratory routes for marine mammals, turtles and birds, and is considered an important nursery ground for fishes. In contrast to the other regions, the waters here are oligotrophic, with low primary productivity and low content of particulate organic matter.

1.2 Local indigenous populations

Within the *Orinoquia* (area related to the Orinoco river covering Venezuelan and Colombian territories), a total of 17 ethnic groups and cultures have been reported, but within the Orinoco Delta, the dominant group are the *Warao* (the "canoe people", or "low-land people"). For the *Warao*, the exploitation of natural resources is a delicate balance between man, nature, and supernatural beings. Any intervention by man must be compensated so the harmony between these three dimensions is maintained. In this way, they alternate the use of natural resources through permanent and through temporal settlements, their habitat, or entourage being the most important spatial concept. The *Waraos* are natural sailors with their *curiaras* (long canoes made of wood). Their main source of protein comes from fishing, but they also grow wild plants (*moriche* palm) and other cultivated plants such as banana, sugar cane and yucca. Besides obtaining starch from the *moriche* palm, they work to obtain the fibers with which they build baskets, roofs, *chinchorros* (hammocks), and fishing gear. Their hunting of terrestrial animals is limited to rodents and birds. The *Warao* population in the Orinoco Delta was nearly 24,000 individuals in the 1990s (Michelangeli, 2000) and grew to 36,027, according to the Venezuelan National Census in 2001, of which more than 75% still speak the *Warao* language. This is the second largest ethnic group in Venezuela, and constitutes 25% of the population of the Delta Amacuro state. The *Warao* villages are built along the edges of the many delta channels, their wooden houses (or *palafitos*) elevated by wood pillars to avoid flooding. Each village is composed of an "extended" family comprising four to five generations (~120 people). These small communities driven by marriage and movement are considered sub-tribes (Michelangeli, 2000). About 202 *Warao* villages have been reported in four of the seven subregions mentioned above: Sac of the Gulf of Paria, Pedernales, Boca de Serpiente, and Boca Grande (Klein & Cárdenas, 2009). Throughout the 20th century and still at present, the Warao have been subject to several socio-cultural, religious, and environmental impacts that have brought important changes to their lifestyle, mostly with negative consequences (García Castro & Heinen, 1999; García Castro, 2000). In 2009, an area of 12 km² around each of the 202 villages was suggested as a conservation area to protect the *Warao* and their settlements, as well as the area under their direct use and influence, aiming to preserve their environment and the use they give to biodiversity, either for subsistence or for cultural reasons (Klein & Cárdenas, 2009).

2. Brief history of research and species discovery in the region

A bibliographic database containing 2,430 references within the time period of 1838 to 2008 was built and analyzed. The first recorded study was by Alexander von Humboldt (Humboldt, 1838) on the morphology, anatomy, distribution, and use of Orinoco manatees. During the late 1800s, a few works described the physical conditions of the Gulf of Paria (e.g. Guppy, 1895a) and provided records on mollusks (Guppy, 1895b, 1895c). Between 1900 and 1950, scientific literature related to the biodiversity of the area is very scarce with occasional

reports mainly on fishes (Fowler, 1911, 1912, 1931), mollusks (Baker, 1923, 1925, 1927), and birds (Phelps & Phelps, 1950a, 1950b; Zimmer & Phelps, 1950). Between 1950 and 2000, a significant increase of studies in the region occurred with a commensurate amount of scientific literature was produced (Figure 2). The themes of these publications are variable

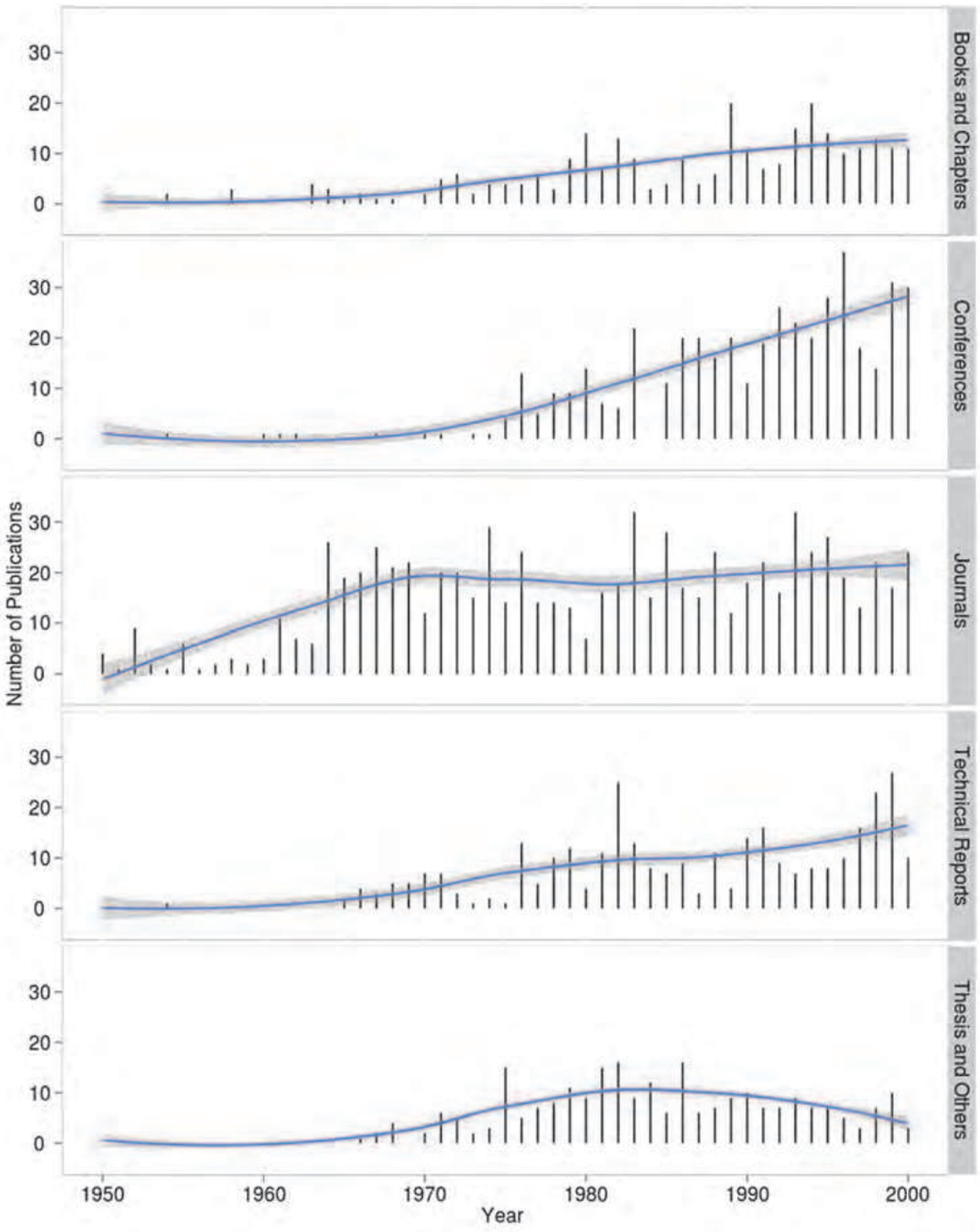

Fig. 2. Number of publications in books, conferences, journals technical reports, thesis and others between 1950 and 2008 related to the Orinoco Delta and the Gulf of Paria.

and range from the abiotic to the biotic. In general, the number of publications has increased for most of the themes, with studies related to fish and fisheries the most prolific (Figure 3).

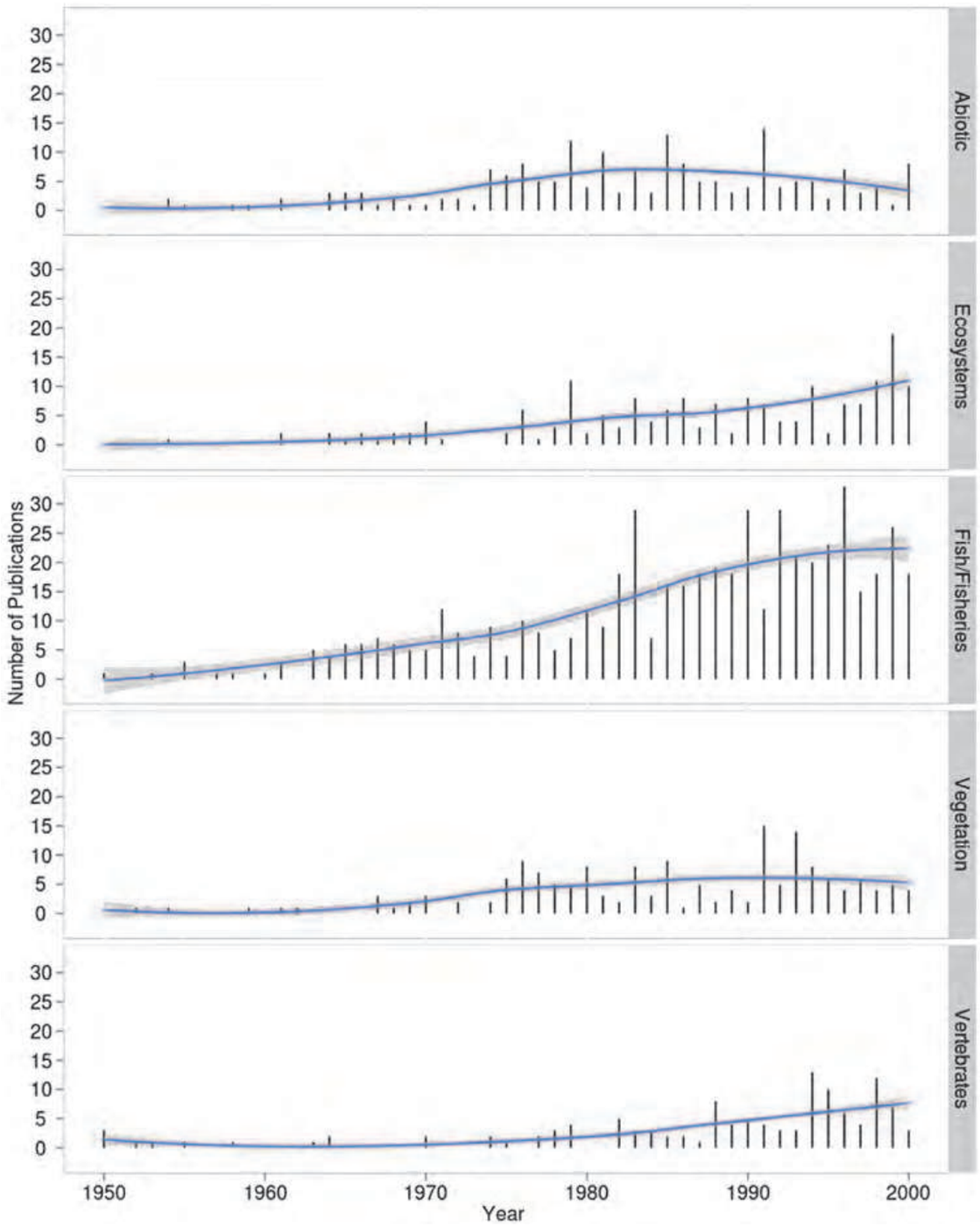

Fig. 3. Number of publications by themes between 1950 and 2008 related to the Orinoco Delta and the Gulf of Paria.

La Salle Foundation of Natural Sciences (FLSCN) has the longest tradition of research in this area (Cervigón, 1965; Ginés & Cervigón, 1968; Ginés et al., 1971, 1972; Lasso, 1993; Monente & Colonnello, 1997, 2004; Ponte & Mochcco, 1997; Jorgensen et al., 2000; Lasso et al., 2002, 2004a, 2004b, 2008, 2009; Lasso & Meri, 2003; Martínez-Escarbassiere et al., 2003; Colonnello, 2004; Lasso-Alcalá et al., 2005a, 2005b, 2008, 2009; Achury et al., 2006; Lasso-Alcalá & Lasso, 2007; Schneider et al., 2007; Lasso & Sánchez-Duarte, 2011),, and in more recent years, due to the pressure from gas and oil companies to carry out offshore exploitation in the area, more institutions have become involved. Despite the great research effort completed, projects carried out in this region have been very focused, geographically localized and punctual in time (no time series data) as well as very isolated. The area is very vast, so most of it remains largely unexplored. As for biodiversity, the best known groups are the fish, mollusks, and crustaceans, groups that are of economic importance, and other vertebrates such as birds and mammals, as well as plants (mangroves).

3. Marine and estuarine biodiversity of the region

The total number of species reported in the region is 2,118, of which 27% are planktonic species (not represented in the benthic community), 38% benthic, 21% fish, and nearly 15% other vertebrates. As in other 26 coastal regions of the world (Costello et al., 2010), half of all species richness is contributed by three groups: fish, crustaceans, and mollusks. Unlike these other 25 regions across the globe, where the contribution of other vertebrates, mainly mammals, reptiles and birds averaged only 2% and at most 8%, in the Orinoco Delta, the contribution of these groups is much higher, due to the extremely high bird species richness in this region (Martín & Bone, 2007). The following sections develop further the present knowledge of biodiversity of the different communities of the Orinoco Delta.

3.1 Invertebrates

3.1.1 Benthos

A total of at least 809 species-level taxa have been reported on benthic communities, from 5 animal phyla, 2 plant phyla (algae and angiospermae: mangroves and seagrasses) and only one group of protists (Foraminifera). Within these benthic communities, the group with the highest diversity is the crustaceans, with 310 species and 91 families reported, with amphipods and decapods comprising the greatest number (or highest percentage). The amphipod species are mainly marine, while decapods are represented by both marine and estuarine species. Mollusks represent the second most diverse group, with 189 species and 83 families, comprised of gastropods and bivalves (Table 1).

Phytobenthos are dominated by benthic algae, with 135 species and 33 families. Although eight seagrass species have been reported for the coast of Venezuela, none has been reported for the delta, only for the Gulf of Paria (Vera, 1992). The absence of seagrasses and benthic macroalgae might be a consequence of high loads of suspended matter and a lack of suitable substrates (Conde, 2000). The dominant terrestrial vegetation of the delta is the mangroves, with a mangrove formation between the Gulf of Paria and the Orinoco Delta representing more than 73% (183,500ha) of Venezuela's mangrove forest (Conde & Alarcón, 1993). Dominant mangrove species are the red mangrove *Rhizophora mangle*, the black mangrove *Avicennia germinans* and the white mangrove *Laguncularia racemosa*, though *R. harrisonii* and *R. racemosa*, the other two species of red mangrove have also been reported for the mid-delta (Pannier, 1979; Conde & Alarcón, 1993).

Kingdom	Phylum or Class	Class or Order	Described families	Described species	State of knowledge
Protista	Foraminifera		13	29	2
Plantae	Algae	Chlorophyta	7	23	3
	Algae	Phaeophyta	4	13	3
	Algae	Rhodophyta	22	99	3
	Angiospermae	(mangroves)	3	5	4
	Angiospermae	(seagrasses)	1	1	4
Animalia	Cnidaria	Scyphozoa	1	1	1
	Sipuncula		4	10	1
	Annelida	Polychaeta	39	94	3
	Mollusca	Bivalvia	30	83	3
	Mollusca	Cephalopoda	4	9	2
	Mollusca	Gastropoda	48	96	3
	Mollusca	Scaphopoda	1	1	1
	Crustacea	Amphipoda	32	143	3
	Crustacea	Cumacea	2	3	1
	Crustacea	Decapoda	43	142	3
	Crustacea	Isopoda	10	18	1
	Crustacea	Stomatopoda	1	1	1
	Crustacea	Tanaidacea	3	3	1
	Chelicerata	Pycnogonida	1	1	1
	Echinodermata	Asteroidea	4	13	3
	Echinodermata	Crinoidea	2	3	1
	Echinodermata	Echinoidea	4	9	2
	Echinodermata	Holothuroidea	3	2	1
	Echinodermata	Ophiuroidea	6	7	1
TOTAL			**288**	**809**	

Table 1. Number of benthic foraminifera, plant, and invertebrate species and families reported in the Orinoco Delta region. State of knowledge classified as: 5 = very well known (>80% described, and current taxonomic expertise); 4 = well known (>70% described, some taxonomic expertise); 3 = poorly known (<50% species described, no present expertise within region); 2= very poorly known (only few species recorded, no expertise); 1 = unknown (no species recorded, no expertise).

3.1.2 Plankton

The phytoplankton community in the area is comprised of Bacillariophyta with 150 species, Pyrrophycophyta (70 species), Cyanocophyta (39 species), Chlorophyta (24 species), Euglenophyta (6 species), and Crisophyta (3 species). Phytoplankton are distributed within two zones: the first dominated by an estuarine community, represented mainly by dinoflagellates, diatoms and chlorophytes, while the second consists of a marine habitat in which marine diatoms make up almost 80% of the community assemblage (Martín & Bone, 2007).

The zooplankton community in the area consists of 283 species of which 211 are crustaceans. Copepods dominate the holoplanktonic component with 116 species. Other groups are the gelatinous organisms, such as the hydrozoans (29 species) and the jellyfish (2 species).

Within the meroplankton, a total of 136 species have been reported, of which the decapod larval stages are the most important and diverse component. These larvae include species of shrimps with commercial value, such as species of the genus *Farfantepenaeus*, bivalves, barnacles and polychaetes (Table 2).

Kingdom	Phylum or Class	Class or Order	Described families	Described species	State of knowledge
Monera	Cyanophycota		8	39	1
Plantae	Bacillariophyta		33	150	4
	Chlorophyta		7	24	1
	Crisophyta		2	3	1
	Euglenophycota		1	6	1
	Pyrrophycophyta		14	70	3
Animalia	Cnidaria	Hydrozoa	15	29	1
	Cnidaria	Scyphozoa	2	2	1
	Ctenophora	Beroida	1	1	1
	Annelida	Polychaeta	5	9	1
	Mollusca	Gastropoda	6	10	1
	Crustacea	Amphipoda	21	54	3
	Crustacea	Branchiopoda	3	3	1
	Crustacea	Copepoda	30	116	3
	Crustacea	Decapoda	1	2	1
	Crustacea	Diplostraca	5	7	1
	Crustacea	Euphasiacea	1	12	2
	Crustacea	Isopoda	2	2	1
	Crustacea	Mysida	1	1	1
	Crustacea	Sessilia	1	6	1
	Crustacea	Stomatopoda	4	6	1
	Crustacea	Tanaidacea	2	2	1
	Echinodermata	Holothuroidea	1	1	1
	Chaetognatha		3	10	1
	Chordata	Appendicularia	2	8	1
	Chordata	Urochordata (Thaliacea)	2	2	1
TOTAL			**173**	**575**	

Table 2. Number of planktonic invertebrate species and families reported in the Orinoco Delta region. State of knowledge classified as in Table 1.

3.2 Vertebrates

3.2.1 Fishes

A total of 438 species have been reported in the Orinoco delta, grouped in 20 orders and 82 families. The best represented groups are the orders Characiformes, Perciformes, and Siluriformes with 132, 99 and 87 species respectively (Table 3). The five families with the highest species richness are the Characidae (73 species), Cichlidae (24 species), Pimelodidae (24 species), Sciaenidae (23 species), and Loricariidae (17 species) (Lasso et al., 2009; Lasso & Sánchez-Duarte, 2011). Of these identified species, 39 % are marine and estuarine, while 61% are strictly from freshwater habitats.

Orders	Families		Genera		Species	
	Number	%	Number	%	Number	%
Carchariniformes	2	2	2	0.7	2	0.5
Pristiformes	1	1	1	0.4	2	0.5
Myliobatiformes	7	9	10	3.6	15	3.4
Elopiformes	2	2	2	0.7	2	0.5
Anguilliformes	2	2	3	1.1	3	0.7
Clupeiformes	3	4	11	3.9	24	5.5
Characiformes	13	16	73	26.0	132	30.1
Siluriformes	11	13	62	22.1	87	19.9
Gymnotiformes	5	6	20	7.1	34	7.8
Batrachoidiformes	1	1	1	0.4	1	0.2
Lophiiformes	1	1	1	0.4	1	0.2
Atheriniformes	1	1	1	0.4	1	0.2
Cyprinodontiformes	3	4	7	2.5	12	2.7
Beloniformes	2	2	5	1.8	6	1.4
Syngnathiformes	1	1	1	0.4	1	0.2
Synbranchiformes	1	1	1	0.4	1	0.2
Scorpaeniformes	2	2	2	0.7	2	0.5
Perciformes	19	23	68	24.2	99	22.6
Pleuronectiformes	3	4	6	2.1	8	1.8
Tetraodontiformes	2	2	4	1.4	5	1.1
Total	**82**	**100**	**281**	**100**	**438**	**100**

Table 3. Number of fish families, genera, and species reported for the Orinoco Delta.

The ichthyological richness of the delta is third largest within the Orinoquia region, with the internal delta of the Ventuari-Orinoco (Venezuela) and the Estrella Fluvial de Inírida (Colombia) having the highest fish diversity (Lasso et al., 2010a). For the entire Orinoquia region, a total of 993 fish species (including freshwater and estuarine species) have been reported. These are grouped in 19 orders, 74 families, and 422 genera (Lasso et al., 2004c). For ichthyofauna, the Orinoco Delta is one of the best known regions of Venezuela compared to other remote and more continental areas of the Orinoco Basin that support a more complex fish fauna from a taxonomical point of view. Studies on fish span several

Theme	Author
Hydrology, vegetation and environmental Impact	Monente & Colonnello (1997, 2004), Colonnello (2004)
Exploratory fisheries Delta and Guyana	Ginés *et al.* (1971, 1972)
Exploratory fisheries Platform	Cervigón (1965), Ginés & Cervigón (1968)
Exploratory fisheries Delta	Ramos *et al.* (1982)
Artisanal fisheries Warao	Ponte & Mochcco (1997)
Warao ethno-ichthyology	Ponte (1995)
Effects of shrimp trawling fisheries	Novoa (2000a), Lasso *et al*. (2002, 2004b, 2008), Lasso & Sánchez-Duarte (2011)
History and socioeconomy of fisheries	Novoa (1982a, 1982b)
Shrimp and *curito* fisheries	Novoa (1982c, 1982d)
Fisheries catalog for the Delta	Novoa *et al.* (1982), Lasso & Sánchez-Duarte (2011)
Fisheries Delta and Gulf of Paria	Novoa (2000b), Bone *et al.* (2004), Lasso &Sánchez-Duarte (2011)
Fisheries resources Orinoquia	Novoa (2002)
Evaluation of fishing potential	Achury *et al.* (2006), Schneider *et al.* (2007), Lasso-Alcalá *et al*. (2008)
Biology of commercial species	Novoa & Ramos (1982), Lasso & Sánchez-Duarte (2011)
Exploratory fisheries	Ramos *et al.* (1982), Lasso & Sánchez-Duarte (2011)
Taxonomy and bio-ecology	Cervigón (1982), Lasso & Sánchez-Duarte (2011)
Taxonomy, biogeography and ecology	Cervigón (1985), Lasso *et al.* (2009), Lasso-Alcalá &Lasso (2007), Lasso-Alcalá *et al.* (2008), Lasso & Sánchez-Duarte (2011)
Trophic ecology	Ponte (1990)
Biogeography	Cervigón (1985), Lasso (1993), Lasso & Sánchez-Duarte (2011)
Biodiversity Orinoco Delta	Ponte *et al.* (1999), Lasso-Alcalá & Lasso (2007), Lasso *et al*. (2009), Lasso & Sánchez-Duarte (2011)
Biodiversity Morichal Largo	Antonio & Lasso (2003)
Biodiversity and community ecology	Ponte & Lasso (1994), Jorgensen *et al.* (2000), Lasso *et al.* (2002), Lasso-Alcalá *et al.* (2008), Lasso & Sánchez-Duarte (2011)
Community ecology Gulf of Paria	Lasso & Meri (2003), Lasso-Alcalá *et al.* (2008), Lasso & Sánchez-Duarte (2011)
Community ecology Delta	Lasso *et al.* (2004 a, 2004b), Lasso & Sánchez-Duarte (2011)
Biodiversity Biosphere Reserve Orinoco Delta	Bone *et al.* (2004), Ortaz *et al.* (2007)
Biodiversity Gran Morichal Reserve	Campo (2004)
Biodiversity and ecology	Lasso *et al.* (2008), Lasso & Sánchez-Duarte (2011)
Alien and introduced Species	Martínez-Escarbassiere *et al.* (2003), Lasso-Alcalá *et al.* (2005a, 2005b, 2009), Lasso & Sánchez-Duarte (2011)

Table 4. Summary of the main publications by theme related to the Orinoco Delta, the Gulf of Paria, and the Venezuelan Atlantic Front.

areas: biology, ecology, fisheries, biogeography, taxonomy, and biodiversity, among others (Table 4). The freshwater fish fauna of the Orinoco Delta results from the combination of the ancestral biota of the Guayanas with the more recent savannah ("*llanera*") biota. On the other hand, the estuarine and marine ichthyofauna found from the Gulf of Paria and the South of Trinidad down to the Amazon river is very uniform (Cervigón, 1985). Toward the northern Venezuelan coast, this situation changes drastically. All the species that are characteristic of the estuarine zone of the delta almost disappear, with the exception of a few euryhaline species that inhabit either positive or negative estuaries, and other species that are mainly marine as adults, but their larvae and juveniles frequent brackish waters. In the Maracaibo lake, another large estuarine system located in the western Caribbean coast of Venezuela, these same estuarine species that had not been reported along more than 2,000 km of coast are present again, showing an important affinity in the fish fauna of the Maracaibo Lake and the Orinoco Delta. According to Cervigón (1985), this ichthyofaunal affinity in Venezuelan territory seems to extend to the Atlantic coast of Colombia, particularly to the south of Cartagena including the Gulf of Urabá.

3.2.2 Other vertebrates

Several aquatic mammals are widely distributed in the Orinoco Delta area. Amphibians are represented by terrestrial and freshwater species associated with mangrove forests. Birds are highly diverse with 255 species, including 21 orders and 54 families. There is only one endemic species of birds in this area, the black-dotted piculet (*Picumnus nigropunctatus*) (Martin & Bone, 2007). The aquatic birds are grouped in eight orders with 36 species of Charadriiformes, including jacanas, lapwings, plovers, sandpipers, snipes, skimmer, and gull terns; 21 species of Ciconiiformes, like herons, egrets, bitterns, storks, and ibises; 8 species of Procellariformes or petrels; 7 species of Pelecaniformes, including pelicans, boobies, cormorants, darters, and frigatebirds; 7 species of Gruiformes, such as limpkins, wood-rails, crakes, and gallinules; 3 species of Coraciiformes or kingfishers; 2 species of Anseriformes such as screamers and ducks, and one species of Phoenicopteriformes or flamingos.

Delta reptiles are represented by three orders, Crocodilia, Squamata, and Testudines. The most representative species of Crocodilia are the spectacular cayman (*Caiman crocodilus*), and the crocodiles *Crocodylus acutus* and *Crocodylus intermedius*, which are on the IUCN Red List of threatened species under the category of vulnerable and critically endangered, respectively. Marine reptiles are represented by five species of sea turtles, all reported along the Venezuelan coast. The five species are considered to be endangered and are protected by the Venezuelan wildlife protection law (Ojasti, 2005; Guada, 2000; Rodríguez & Rojas-Suárez, 2008). Four of these species nest in the Gulf of Paria, from Irapa to Punta Narizona. The leatherback turtle (*Dermochelys coriacea),* spawns in the Barra Mariusa and Tobejuba area, within the boundaries of the Delta del Orinoco National Park and Reserva de Biosfera Delta del Orinoco. As for mammals, the most common is the freshwater dolphin, *Inia geoffrensis* (tonina), while other species, like the river dolphin, *Sotalia fluviatilis*, the manatee, *Trichechus manatus*, the giant otter, *Petronura brasilienis,* and the long-tailed otter, *Lontra longicaudis,* are rare. The giant otter and the manatee have been reported as critically endangered (Linares, 1998). Only two species of the 13 Cetacea recorded (*Megaptera novaeangliae* and *Balaenoptera physalus*) are considered as vulnerable in the Red List of Venezuelan fauna (Table 5).

Kingdom	Phylum or Class	Class or Order	Order or Family	Described families	Described species	State of knowledge
Animalia	Chordata	Amphibia	Anura	3	6	1
		Aves	Accipitriformes	1	2	1
		Aves	Anseriformes	2	2	1
		Aves	Apodiformes	2	11	1
		Aves	Caprimulgiformes	2	4	1
		Aves	Charadriiformes	5	36	2
		Aves	Ciconiiformes	4	21	1
		Aves	Columbiformes	1	7	1
		Aves	Coraciiformes	1	3	1
		Aves	Cuculiformes	1	7	1
		Aves	Falconiformes	3	18	1
		Aves	Galbuliformes	1	3	1
		Aves	Galliformes	1	1	1
		Aves	Gruiformes	2	7	1
		Aves	Passeriformes	15	94	4
		Aves	Pelecaniformes	4	7	1
		Aves	Phoenicopteriformes	1	1	1
		Aves	Piciformes	2	9	1
		Aves	Procellariformes	3	8	1
		Aves	Psittaciformes	1	8	1
		Aves	Strigiformes	1	4	1
		Aves	Trogoniformes	1	2	1
		Reptilia	Crocodilia	2	4	4
		Reptilia	Squamata	6	12	4
		Reptilia	Testudines	8	14	4
		Mammalia	Carnivora	1	2	2
		Mammalia	Cetacea	4	13	3
		Mammalia	Sirenia	1	1	4
TOTAL				**79**	**307**	

Table 5. Number of vertebrate (amphibians, birds, reptiles, and mammals) species and families reported in the Orinoco Delta region. State of knowledge classified as in Table 1.

4. Threats to marine biodiversity

Any plan to achieve effective conservation of biodiversity and the functionality of the natural systems requires precise knowledge of the sources of actual or potential hazards or pressures and where and how those pressures could affect ecosystems and their components. Such pressures (pollution, resource exploitation, etc.) cause environmental disturbances in a given area, impacting the biological attributes of the biota or physical components of the ecosystem. Threats to biodiversity can then be described as a pressure source, by its spatial coverage, and the intensity of its actual or potential impacts. The Orinoco Delta and the Venezuelan Atlantic Front are very diverse collections of particular marine and coastal ecosystems (mangrove and palm forests, sand barriers, estuary and micro watershed nets, muddy/sandy marine bottoms, demersal fish and crustacean

populations), with relatively limited coastal and marine area (35,000 km²). In general, all these ecosystems are healthy, with minimal disturbance. In this generally pristine landscape, there are some small urban and rural communities, whose presence determines the occupation and use of the area. The delta environment provides several types of resources for the people who live there (Creole and indigenous communities), and, in turn, the residents create different threats to the ecosystems, which in some cases, measurably impacts them.

In addition, in light of recent Venezuelan governmental strategies to boost the economy, the national oil industry has initiated a large scale project for offshore and nearshore gas exploitation, covering more than 25% of Venezuela's territorial sea and EEZ. This development could pose a significant threat to marine biodiversity in the region and to traditional livelihoods of local human populations. Few models have been developed to measure the impact of the human activities on the marine environment.

On a global scale, the model developed by Halpern et al. (2008), propose a 'low cumulative impact score' for the Golfo de Paria and Atlantic Front. In this estimation, impacts for the region generated by fisheries are minor and nonexistent for the oil and gas activities. In a more detailed model with higher spatial resolution (Klein & Cárdenas, 2009), fisheries and oil and gas activities (exploration, production, and decommissioning) have a high incidence in shaping the threats map (Figure 4).

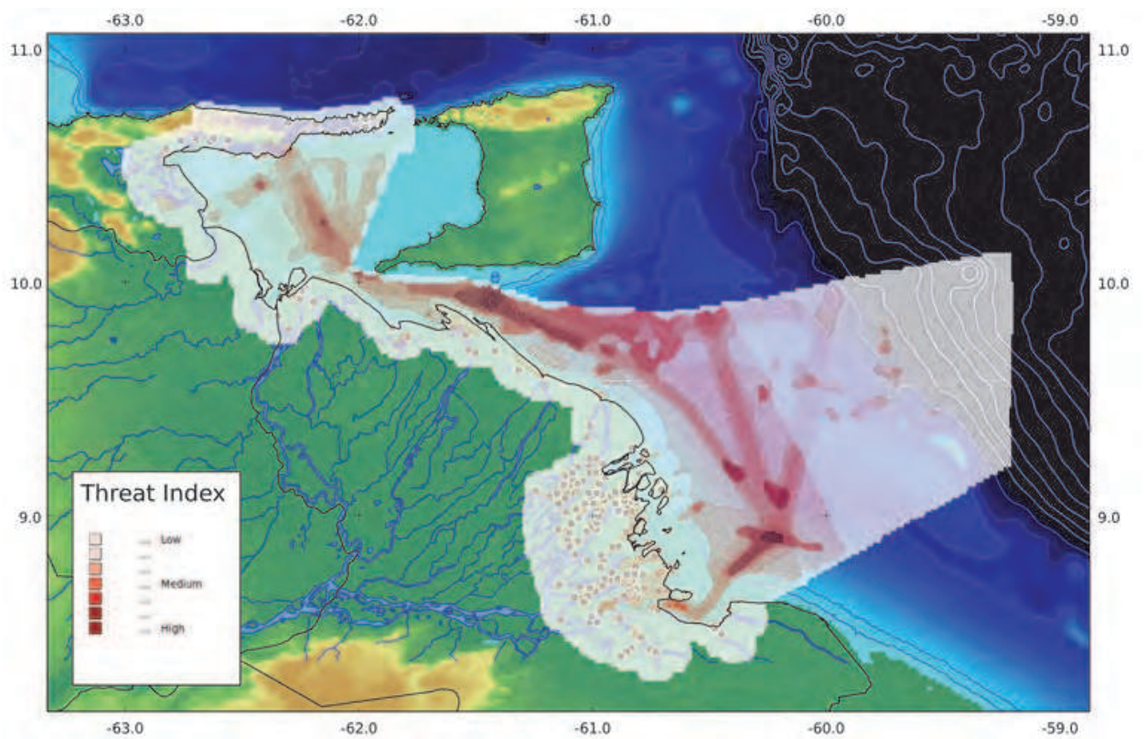

Fig. 4. Map of the Orinoco Delta and Gulf of Paria region in the Venezuelan Atlantic front showing the areas under threat by human activities.

The marine region of the Orinoco Delta supports important fisheries that provide 10,000 tons/year (around 5 % of the total marine national catch). The fishery targets mainly species

Threat	Description of impact
Industrial fisheries	Effects on fish and soft bottom communities produced by poorly controlled extraction of fish and some invertebrates organisms, and the disruption of the bottom sediments produced by trawling nets.
Artisanal fisheries	Effects on fish and invertebrates populations by poorly controlled extraction of organisms by different fishing techniques (traps, seines, small trawling nets, hooks).
Coastal urban development	Impacts generated by human activities such as habitat transformation and destruction, wildlife extraction and commercialization, introduction of non-native species, solid and liquid wastes, noise, etc. Effects depend on the size of human settlements and population density (i.e., large, dense towns, greater impacts).
Agricultural activities	Consider threats due to normal or poorly regulated agricultural activities like habitat transformation, wildlife extraction, introduction of non-native species, solid and liquid wastes, and chemical pollution of land and water bodies.
Channel dredging and flux control	Regular disturbance of soft-bottom benthic communities and increased suspended sediments due to major and maintenance dredging activities in the navigation channels. Regulation of water flux affects natural migration patterns of species.
Water pollution and upper river basin impacts	Water quality alteration due to high loads or regularly elevated loads of pollutants delivered by the river delta. Related to urban and agricultural activities in the upper basin. Effects could be propagated towards the open sea, depending on river discharge.
Mangrove deforestation	Though highly controlled as industrial activities, local extraction of construction material for housing and fishing gear could produce locally important habitat loss of mangrove and its associated communities.
Oil industry activities	Impacts produced by all stages of an oil industry project (exploration, development, exploitation, and decommissioning). Existing and planned activities equally considered.
Ports and marinas	Impact produced by regular activities of vessels at commercial ports including maneuvering, loading and unloading operations, and repairs. Fishing and sport marinas are also considered.
Maritime corridors	Major navigation routes. May serve as dispersion agents for alien species, and pollution sources from bilge water discharges.
Introduction of alien species	Competition, displacement and extinction of local species. Impact on fisheries due to predation of juveniles of commercial species, and on human health (transmission of diseases).

Table 6. Summary of threats to marine and coastal biodiversity and description of their impacts.

of Ariidae, Sciaenidae, Carangidae, Lutjanidae and Scombridae families in waters up to 60m depth. Industrial trawling, which fished mainly for shrimp, was banned in 2009, but artisanal trawling still persists near the coast. Poorly controlled, artisanal trawling represents a major threat to marine coastal biodiversity because of its intensity and the large swath of area it covers in highly sensitive coastal environments.

Although in early stages of development, offshore and nearshore gas reserves represent 2.4% of the total national gas reserves (6-10 TCF). Some structures are already in place (Pedernales subregion) and exploratory offshore drilling is ongoing (Oceanic subregion). Plans are that all gas production is directed to a new inland facility (CIGMA: Industrial Complex Gran Mariscal de Ayacucho) that will be built near Güiria (Península de Paria subregion). This transport and processing complex will directly affect 63 km² of coastal area and indirectly 110 km² of marine area. Its construction and operation will generate an elevated demand of services in what is now a poorly developed area. The environmental impacts of this complex have been evaluated, but little has been done to reduce or mitigate them.

At present, a number of major threats to Venezuelan marine biodiversity have been identified, quantified and mapped (Table 6). The threats and the potentially affected ecosystems can be viewed at http://paria.cbm.usb.ve/mapas/dinamicos , and Martínez-Escarbassiere et al. (2003), Lasso & Sánchez-Duarte (2011) and Lasso-Alcalá et al. (2005a, 2005b, 2009).

5. Conservation initiatives

The Orinoco Delta region has been recognized as one of the most pristine and biodiversity rich environments of Venezuela. Since 1979, three major National Parks have been established, covering a total of 4,385 km². All parks are classified as type II (IUCN, 1994), which mean they are managed mainly for ecosystem protection and recreation. None, however, includes a significant portion of their marine areas. To help rectify this, in 1991, the Orinoco Delta Biosphere Reserve was decreed by the Venezuelan Ministry of the Environment, and designated by UNESCO in 2009, to protect a land and water surface of 11,250 km². The reserve was created to protect the rich biodiversity of plants, animals and cultural features, and encompasses about 4,500 km² of marine and estuarine area. In 2002, a major effort also was made to evaluate the biodiversity of the reserve, and the investigations produced the first integrated and geo-referenced inventory of vegetation, mammals and aquatic and marine biota of the reserve (Bone et al., 2004).

Despite the establishment of the protected areas for the region, a new approach was initiated that considered present and future threats to the area's biodiversity (Klein and Cárdenas, 2010). Using an ecosystem-based model (Possingham et al., 2000), nine areas were proposed for implementation of special conservation strategies (priority conservation areas or PCA). This approach took into account the health status and vulnerability of the main ecosystems, and their populations, and the costs of implementing viable conservation actions, considering the cumulative potential threats for the region. A similar analysis was made for the Venezuela's Caribbean Sea (Klein, 2008). One of the most innovative characteristics of this ecosystem-based model is that it takes into account the future plans of offshore oil and gas development, while recognizing the coexistence of development and

conservation. The proposed portfolio of priority conservation areas would add 17,681 km² of mostly marine areas to the formally protected areas (Figure 5). The proposed PCAs overlap to some extent with existing protected areas, but in many cases, areas not considered before are included. Although these additional PCAs have not been formally adopted by an official environmental agency, the associated conservation strategies are being used by the oil industry in planning their operations.

Considering the remoteness and limited accessibility of most of this region, adequate management of protected areas represents a challenge. In many cases, areas are accessible only by river or by air, although human activities are already taking place. Controlling and surveying the main threats is difficult at best, so their cumulative impacts may affect the biodiversity of the region. A major enforcement effort is necessary to provide basic services needed to guarantee effective implementation of conservation strategies for the region, which could be related to innovative management plans for the current and future protected areas. Such plans should not only regulate the landscape and its elements, but also consider the administration of trans-regional exploited populations, as are the widely distributed fisheries resources.

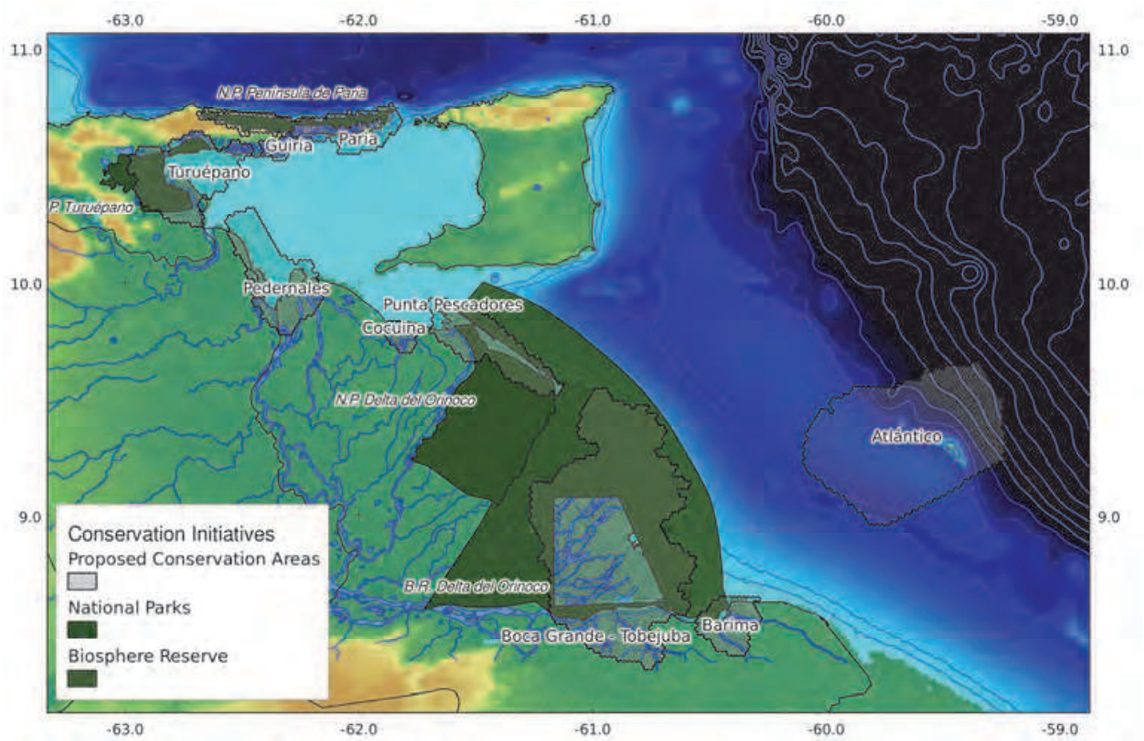

Fig. 5. Map of the Orinoco Delta and Gulf of Paria region in the Venezuelan Atlantic front showing the protected areas (NP= National Parks), the Orinoco Biosphere Reserve declared by UNESCO, and the proposed conservation areas considering present and future threats to biodiversity using an ecosystem based model.

6. Conclusion

The Orinoco Delta and the Gulf of Paria constitute one of the major wetlands in South America and are one of the best preserved ecosystems in the world. These wetlands were formed by the combined action of sediment and freshwater discharges from the Orinoco, one of the longest rivers in South America along with the tides on a flat alluvial plain. Based on physical and chemical characteristics and ecosystems that developed in this area, seven subregions were defined. In the Orinoco Delta, the dominant ethnic group are the *Warao* with a population of more than 36,000 people spread in at least 202 settlements which have been proposed as conservation targets.

The earliest studies of the region began in the 1800s, however, important production of publications did not begin until the mid 1950s and is still increasing today. In the late 1990s and early 2000s, baseline studies were carried out in the area in response to the interest of oil and gas companies in establishing offshore and coastal developments. Nevertheless, despite the great effort of research that has been done, projects carried out in this region have been very focused, geographically localized and punctual in time (no time series data) as well as very isolated, so most of the area remains largely unexplored. As for biodiversity, the best known groups are the fish followed by crustaceans and mollusks which contribute almost 50% of the total species richness, with other vertebrates contributing almost 15% of the total species richness, represented mainly by birds.

Major threats to biodiversity in this region are industrial and artisanal fishing, urban and agriculture development, dredging and flow navigation, water pollution (run off from the Orinoco basin), mangrove deforestation, activities related to oil and gas exploitation, port activities, and maritime transit.

The Orinoco Delta and Gulf of Paria region have two protected areas under special national conservation regulations. These are the Turuépano National Park in the Gulf of Paria, and the Orinoco Delta National Park. Both are under IUCN conservation category II, meaning they are managed mainly for ecosystem protection and recreation. An important area of the Orinoco Delta is also considered a Biosphere Reserve by UNESCO. Considering present and future threats to the area's biodiversity, nine additional priority conservation areas are proposed for implementation of special conservation strategies by using an ecosystem-based model. Although these additional PCAs have not been formally adopted by an official environmental agency, the associated conservation strategies are being used by the oil industry in planning their operations and further development.

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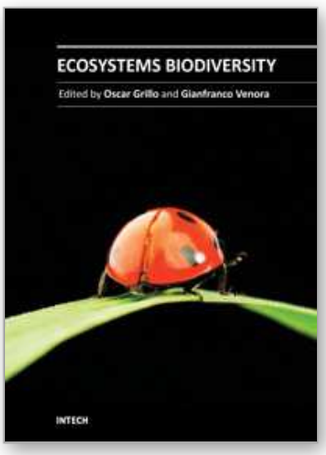

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Ecosystems can be considered as dynamic and interactive clusters made up of plants, animals and micro-organism communities. Inevitably, mankind is an integral part of each ecosystem and as such enjoys all its provided benefits. Driven by the increasing necessity to preserve the ecosystem productivity, several ecological studies have been conducted in the last few years, highlighting the current state in which our planet is, and focusing on future perspectives. This book contains comprehensive overviews and original studies focused on hazard analysis and evaluation of ecological variables affecting species diversity, richness and distribution, in order to identify the best management strategies to face and solve the conservation problems.

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