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Macrofauna from the sandy shore of the Johnny Cay Regional Natural Park, San Andrés and Providencia, biosphere reserve, Colombian Caribbean region

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Abstract

Despite their great importance, the sandy shores have not received the attention deserved. In Colombia they have been approached mainly from physical and geological standpoints, with few studies on the associated biodiversity, as is the case of the Johnny Cay Regional Natural Park in the Colombian Caribbean Region. To have a future frame of reference to evaluate and monitor the environmental impact on the sandy coast of Johnny Cay, the macrofaunal community of this ecosystem was characterized. Two stations were established, where three sediment samples were taken per beach zone (infralittoral, mesolittoral, and supralittoral), using a 16 cm diameter core, for a total of nine samples per station. The samples were sieved through a 500 µm mesh and processed in a laboratory. The macrofaunal community of Johnny Cay was represented by 1628 organisms, belonging to 20 families of the phyla Annelida, Nematoda, Mollusca, and Arthropoda (subphylum Crustacea). Annelids were the dominant group, representing 98% of total abundance, with two new family reports (Naididae and Enchytraeidae) for the Colombian Caribbean sandy beaches. The station EST_549 presented 67% of the macrofauna; this station is characterized by its hydro-dynamism, with a change of material due to the division in the opposite direction of the waves. Substrate samples were also taken in each beach zone for sedimentological analysis of grain size, carbonate content, organic matter content, and mineralogy; these variables were correlated with the community structure, obtaining a better correlation between the medium and coarse sands, and the width of the beach zone with the biological component. This work presents the baseline for the macrofaunal community of Johnny Cay sandy shore and sets the initial steps for its preservation and conservation.

Keywords: Ecology, Sandy beaches, Infauna, Biodiversity, Insular Caribbean

INTRODUCTION

Sandy shores represent dynamic environments in which waves, tides, and wind engage with sediment, creating a distinctive habitat for numerous endemic species of fauna and flora that have developed a range of adaptations to thrive in this morphodynamically evolving ecosystem. Furthermore, they determine three different beach zones or microhabitats: supralittoral, mesolittoral, and infralittoral, which vary among themselves in terms of their morphology, sedimentary processes, and interactions with abiotic agents (Stephenson and Stephenson, 1949; McLachlan and Brown, 2006; Mclachlan and Defeo, 2018).

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The supralittoral, also referred to as the splash zone, is situated above the high tide line and generally remains dry, being affected only by the spray of the waves. It typically features formations such as dunes, berms, and terrestrial vegetation, serving as a significant nesting area for turtles and shorebirds. The mesolittoral zone is confined between the high and low tide lines, thus being influenced by the tide-dominated hydrographic regime; this zone occupies a narrow strip along the microtidal Caribbean coasts. Lastly, the infralittoral zone spans from the low tide line, including the turbulent "surf" zone, to the completely submerged area. It stands out as the most diverse zone in terms of marine species and functional groups (Defeo et al., 2009).

Beyond their significance for associated biodiversity, sandy coastlines provide several ecosystem services (Harris and Defeo, 2022), such as sediment storage and transport, and wave dissipation, acting as a buffer against extreme events such as storms and tsunamis. Additionally, sandy beaches provide recreational opportunities and serve as food resources for humans, thus having an economic importance for local communities. The shores also play a vital role in the decomposition of organic matter and pollutants, water filtration and purification, mineralization, nutrient recycling, water storage in dune aquifers, and groundwater discharge; furthermore, sandy beaches contribute to the maintenance of biodiversity and genetic resources, establishing functional links between terrestrial and marine environments in the coastal zone (Schlacher et al., 2008; Defeo et al., 2009; McLachlan and Defeo, 2018).

Over the last decade, the ecological importance of sandy shores has gained interest, driven by the impacts of climate change and anthropogenic activities, such as pollution, sand mining, deforestation, exploitation of coastal species, and urban development and excessive tourism are particularly the most prevalent, due to the increasing demand for leisure time (Harley et al., 2006; Schlacher et al., 2008; Fanini et al., 2020; Defeo et al., 2021; McLachlan and Brown, 2002). However, ecological aspects of beaches are rarely considered as significant environmental indicators in the formulation of conservation, monitoring, and control strategies (Defeo et al., 2009), thus this lack of emphasis is attributed to the global prioritization of other coastal ecosystems, including rocky shores, mangroves, and coral reefs (Fairweather, 1990; McLachlan and Brown, 2006; Schlacher et al., 2008).

Colombia has a privileged geographical position, with coasts on the Atlantic and Pacific oceans, of which approximately 865 km are sandy coasts (407 km on the Caribbean coast and 458 km on the Pacific coast) (Ceballos, 2009; Gómez-Cubillos et al., 2015). Despite this, knowledge of the biodiversity associated with sandy beaches is still incipient, with few studies conducted to characterize the benthic communities in this environment (For the Pacific: Riascos and Rallón, 2001; Riascos, 2002; Valencia et al., 2023; and for the Caribbean: Dexter, 1974; Cortés-Useche and Mendoza, 2012; Yepes-Gaurisas et al., 2017; Lagos et al., 2018; Castro et al., 2021), and for the insular Caribbean region, this study in Johnny Cay would be the first.

Considering the need to strengthen ecological understanding of coastal biomes, and recognizing the potential benthic organisms as ecological bioindicators to assess marine ecosystems (Checon et al., 2023), the Johnny Cay Regional Natural Park, belonging to San Andrés, Providencia, and Santa Catalina Archipelago, has been selected as the study area, where the deterioration and loss of marine and coastal ecosystems are related to urban expansion and tourism infrastructure on its main islands (Gómez- López et al., 2012). The main objective of this study was to characterize the macrofaunal community of the sandy beach of Johnny Cay, and to assess its correlation with environmental variables, establishing a referential framework that enables the evaluation and monitoring of potential negative impacts on the habitat of these infaunal marine invertebrates.

METHODS

Study area

The archipelago of San Andrés, Providencia and Santa Catalina, in Western Caribbean, 775km

away from the northern coast of Colombia, is the northernmost territory in the country. This archipelago is part of a submarine mountain range which extends between Nicaragua and the islands of Jamaica, Haiti, and Dominican Republic, and comprises three major islands (San Andrés, Providencia, and Santa Catalina), five banks (Alicia, Quitasueño, Nuevo, Roncador, and Rosalinda, the latter not administered by Colombia), and 16 cays, including Johnny Cay (Posada et al., 2011). Johnny Cay (JC) has formed by the accumulation of skeletons of primitive corals (Aguilera Díaz, 2010) and has an approximate area of 44.24 ha; only 12% of this area consists of land with terrestrial vegetation and sandy beach zones, while the remaining 88% is submerged marine territory (Vides et al., 2017; Vides and Alonso, 2018), characterized by seagrasses, macroalgae, and primarily barrier and fringe coral reefs (Figure 1).

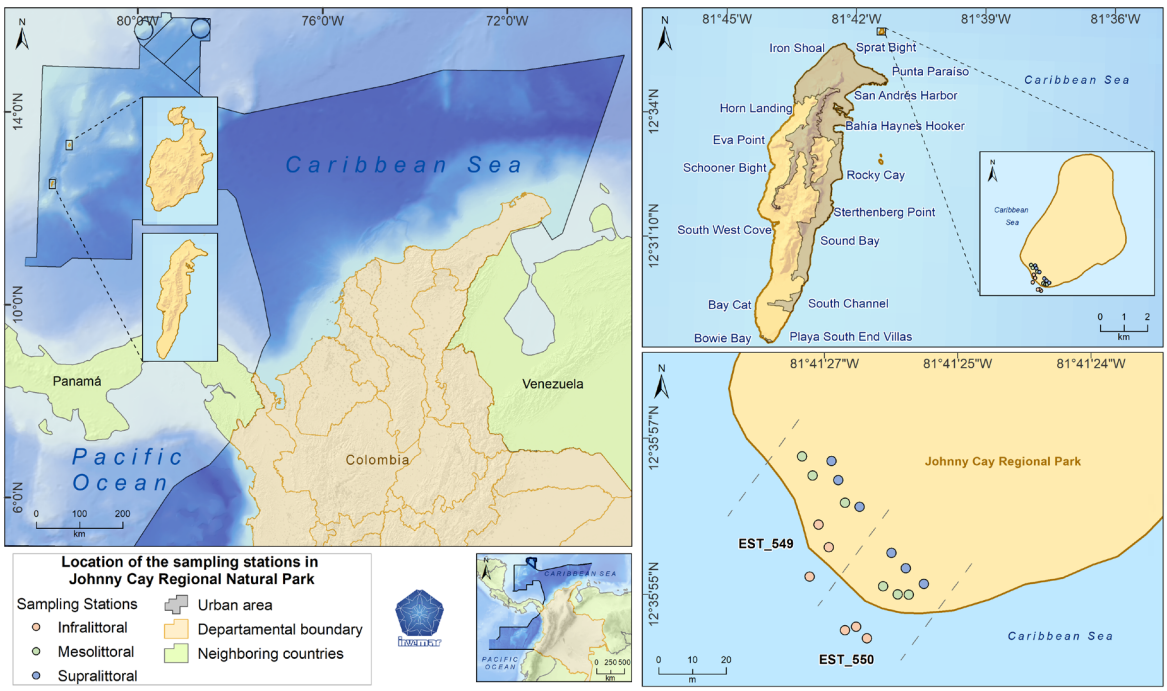

Figure 1. Study area in the Johnny Cay Regional Natural Park in the Colombian Caribbean Region. The location of the collected cores is shown by stations and beach area.

In 2001, Johnny Cay and its surrounding reef complex, were designated as a Regional Natural Park (RNP) in a government-led initiative to address and mitigate the degradation of hydrobiological resources and ecosystems within area, including its sandy beach system, which experiences significant pressures from recreational activities (Providence Foundation, 2015).

The predominant portion of Johnny Cay Regional Natural Park (JCRNP) sandy coastline is situated at the southern section of the cay, and it is a highly dynamic beach, with winds and currents exerting constant influence on both the submerged and emerged parts of the coastline. Salinity of the surrounding waterbody displays seasonal variations with a 34-35 ppt mean; water temperature falls within 28 to 29°C, pH levels range between 8.08 and 8.15, and dissolved oxygen content exceeds 6.5 mg L^{-1}.

Fieldwork

Jhonny Cay Regional Natural Park was visited in August 2017 during the project "Biological baseline of the Jhonny Cay Regional Natural Park, San Andrés Island, Biosphere Reserve" conducted

by the Marine and Coastal Research Institute "José Benito Vives de Andréis" – INVEMAR – in collaboration with the Corporation for the Sustainable Development of the Archipelago of San Andrés, Providencia, and Santa Catalina (CORALINA) (Vides et al., 2017). In the field, two sampling stations (EST_549 and EST_550) were established, in the broadest section of the sandy coastline of the cay, considering that these are areas in one of the most crowded spaces on the beach. The supralittoral, mesolittoral, and infralittoral zones were identified and physicochemical parameters including water temperature, dissolved oxygen, and saturated oxygen in the infralittoral zone were measured, as well as sediment temperature in the mesolittoral and supralittoral zones. Beach features such as the width of each zone, the presence of people, footprints, decapods, and other pertinent data to understand the dynamics of the area were recorded.

For macrofauna characterization, sediment samples were randomly collected using a 16 cm-diameter PVC core (0.020 m^2), thrice per beach zone, obtaining a minimum sediment column of 20 cm, and totaling nine samples per station. Each sediment sample was sieved through a 500 µm mesh (Eleftheriou, 2013); after, a magnesium chloride solution was added to anesthetize and relax the organisms, and then they were fixed with a 12% formalin solution (37% formaldehyde, borax, rose bengal, and filtered seawater).

In addition, a 100 g sediment sample was collected per beach zone at each station for sedimentological analysis (grain size, carbonate content, organic matter content, and mineralogy). These samples were processed and analyzed by the Geosciences (GEO) program at the INVEMAR, according to their protocols and methodologies established for each parameter (Coca-Domínguez and Ricaurte-Villota, 2017).

Laboratory work

In the laboratory, sediment samples were washed and sieved (500 µm) to remove formalin and remaining fine sediment fractions. Macrofaunal organisms were separated from the sediment, quantified and taxonomically identified, using taxonomic keys corresponding to each phylum and optical equipment such as stereomicroscopes and compound microscopes. All the specimens were preserved in 70% alcohol and deposited in the corresponding biological collections within the Marine Natural History Museum of Colombia (MHNMC) – Makuriwa of INVEMAR. The information associated with these deposited specimens is documented in the Marine Biodiversity Information System (INVEMAR – SiBM, 2019).

The identifications were made at the most specific taxonomic level possible, using the works of De Leon Gonzalez et al. (2009) for annelids, Diaz and Puyana (1994) for mollusks, McKinney (1978) and Hoover and Bousfield (2001) for crustaceans, and Keppner and Tarjan (1989) and Platt and Warwick (1983) for nematodes.

Data analyses

The macrofaunal community was described by abundance and richness; spatial patterns between beach zones and stations were evaluated with a non-parametric multidimensional scaling (nMDS) analysis implementing the Bray-Curtis similarity index. An ANOSIM (similarity analysis) was performed to corroborate statistically significant groupings.

Correlation between the community structure and environmental variables collected in all beach zones was analyzed using BIOENV statistical routine. All statistical analyses were performed using Primer v6 software (Clarke and Gorley, 2006).

RESULTS

The infaunal community on the Johnny Cay Sandy Beach was represented by a total of 1.628 macrofaunal organisms belonging to 20 families of phyla Annelida, Nematoda, Mollusca, and subphylum Crustacea (phylum Arthropoda), for a total density of 4.514 ± 1.871 individuals m^{-2} (mean ± standard error). Annelids dominated the sediment regarding both richness (11 families) and abundance (1598 individuals), representing 98% of the total macrofauna. Nematodes constitute the second most represented group, encompassing seven families, and with a density of 58 ± 25 individuals m^{-2} (Table 1).

Table 1. Relative frequencies (RF), frequencies of occurrence (FO), and total abundance (TA), of each family by phylum, found in the macrofaunal community of Johnny Cay Regional Natural Park, Colombian insular Caribbean Region.

Phylum	Families	EST_549			EST_550			Total	Relative frequency (%)	frequency of occurrence (%)
		infralittoral	mesolittoral	supralittoral	infralittoral	mesolittoral	supralittoral			
Annelida	Saccocirridae	85	16	2	0	35	0	138	8.5	67
Annelida	Enchytraeidae	0	94	812	0	0	94	1000	61.5	50
Annelida	Syllidae	32	1	0	2	3	0	38	2.3	67
Annelida	Phyllodocidae	14	0	0	14	0	0	28	1.7	33
Annelida	Protodrillidae	0	13	0	0	340	0	353	21.7	33
Annelida	Naididae	0	0	0	0	35	0	35	2.2	17
Annelida	Sigalionidae	0	0	0	2	0	0	2	0.1	17
Annelida	Capitellidae	1	0	0	0	0	0	1	0.1	17
Annelida	Nereididae	0	1	0	0	0	0	1	0.1	17
Annelida	Opheliidae	0	0	0	1	0	0	1	0.1	17
Annelida	Polygordiidae	0	0	0	0	1	0	1	0.1	17
Nematoda	Thoracostomopsidae	9	1	1	1	0	0	12	0.7	67
Nematoda	Oxystominidae	1	0	0	0	0	0	1	0.1	17
Nematoda	Oncholaimidae	1	1	0	1	1	0	4	0.2	67
Nematoda	Cyatholaimidae	1	0	0	0	0	0	1	0.1	17
Nematoda	Neotonchidae	1	0	0	0	0	0	1	0.1	17
Nematoda	Selachinematidae	1	0	0	0	0	0	1	0.1	17
Nematoda	Leptosomatidae	0	0	0	1	0	0	1	0.1	17
Mollusca	Littorinidae	0	0	0	1	0	0	1	0.1	17
Arthropoda	Amphilochidae	5	0	0	0	0	0	5	0.3	17

Station EST_549 showed the highest number of individuals (1.095) and families (18), within Annelida, Nematoda, and Mollusca phyla, with a density of 6.078 ± 212 individuals m^{-2} (Average ± SD), whereas Station EST_550 showed a lower abundance and richness, with 533 organisms from 14 families including annelids, nematodes, and crustaceans, reporting a density of 2.950 ± 81 individuals m^{-2} (Table 1). EST_549 station is in a marine terrace with high hydrodynamics, and slopes between 10° and 16° on the beachfront and 47.6° on the infralittoral, with a change of material caused by the division in the opposite direction of the waves, forming "Beach Cusps," a common feature for stable beaches. Otherwise, EST_550 station is in a more unstable area, located on a beach cup (heights between 5 and 7.5 m) with a gentle slope of 5.11° to 10.1°. This area serves as a local dock for tourism, and is therefore more influenced by anthropic impacts.

Regarding annelids, Protodrillidae and Enchytraeidae were the dominant families, representing 61.5 and 21.7% of the relative frequency, respectively (Table 1), without presenting the greatest occurrence between the stations or their zones. In contrast, Saccocirridae and Syllidae (Figure 2), whose relative frequencies were 8.5 and 2.3% of the total macrofauna found, respectively, exhibited the highest frequencies of occurrence. The record of other Annelida families was variable between stations and zones, reporting a maximum richness of five families both in the mesolittoral and infralittoral, and between one and two families in the supralittoral of both stations. The Nematoda phylum exhibited a relative abundance of 1.47%, and despite its lower density compared with Annelida, it demonstrated a high frequency of occurrence, particularly represented by the Thoracostomopsidae and Oncholaimidae families. Other families, such as Neotonchidae, Selachinematidae, and Cyatholaimidae, showed lower frequencies (Figure 3). Abundances of other taxa within Nematoda were minimal, and their occurrences spanned across beach zones in both stations (Table 1). In contrast, mollusks and crustaceans, recorded in a single beach zone of different stations with only one family each, displayed low relative abundances and frequencies of occurrence (Table 1).

The nMDS analysis revealed a distinct grouping trend by beach areas rather than stations, indicating a similarity in the community structure within the supralittoral zones of both stations; a similarity that is extended to the mesolittoral and infralittoral zones (Figure 4). Particularly, these last two zones exhibited smaller distances between them in the graphic pattern, suggesting an association, which is possibly due to environmental factors such as the wave effect and a constantly submerged or wet sediment. The analysis presented a stress value of 0.01, designated as excellent on the Clarke and Warwick (1990) scale (Figure 4). The analysis of similarities between the observed assemblages (ANOSIM) showed a global R of 0.833 and a level of statistical significance of 6.7%, indicating that the trend detected is clear and strong; however, these groupings are not statistically significant. The R-value clarifies that the similarities within each zone are high, but the significance value denotes that the structural differences due to richness and abundance variations in these microhabitats are not large enough to be considered distinct assemblages.

Sediment composition of the cay consists mainly of biogenic material associated with coral fragments, coarse and very coarse sand, and high carbonate and low organic matter content (Table 2). Correlation between morphodynamical variables and the community structure shows that medium and coarse sand, beach zone width, organic matter, and carbonate content are key factors. The BIOENV analysis identifies "medium sand," "coarse sand," and "beach zone width" as the top correlated variables, although not statistically significant (R: 0.39; significance level: 66.4%); This suggests that other unconsidered variables, such as beach morphodynamics (Dean's parameter), wind speed, air temperature, significant breaker height and period, tidal regime, wave climate, turbidity, and historical processes, may play a more influential role in shaping the community structure of these ecosystems (Nielsen et al., 2013; Carcedo et al., 2015).

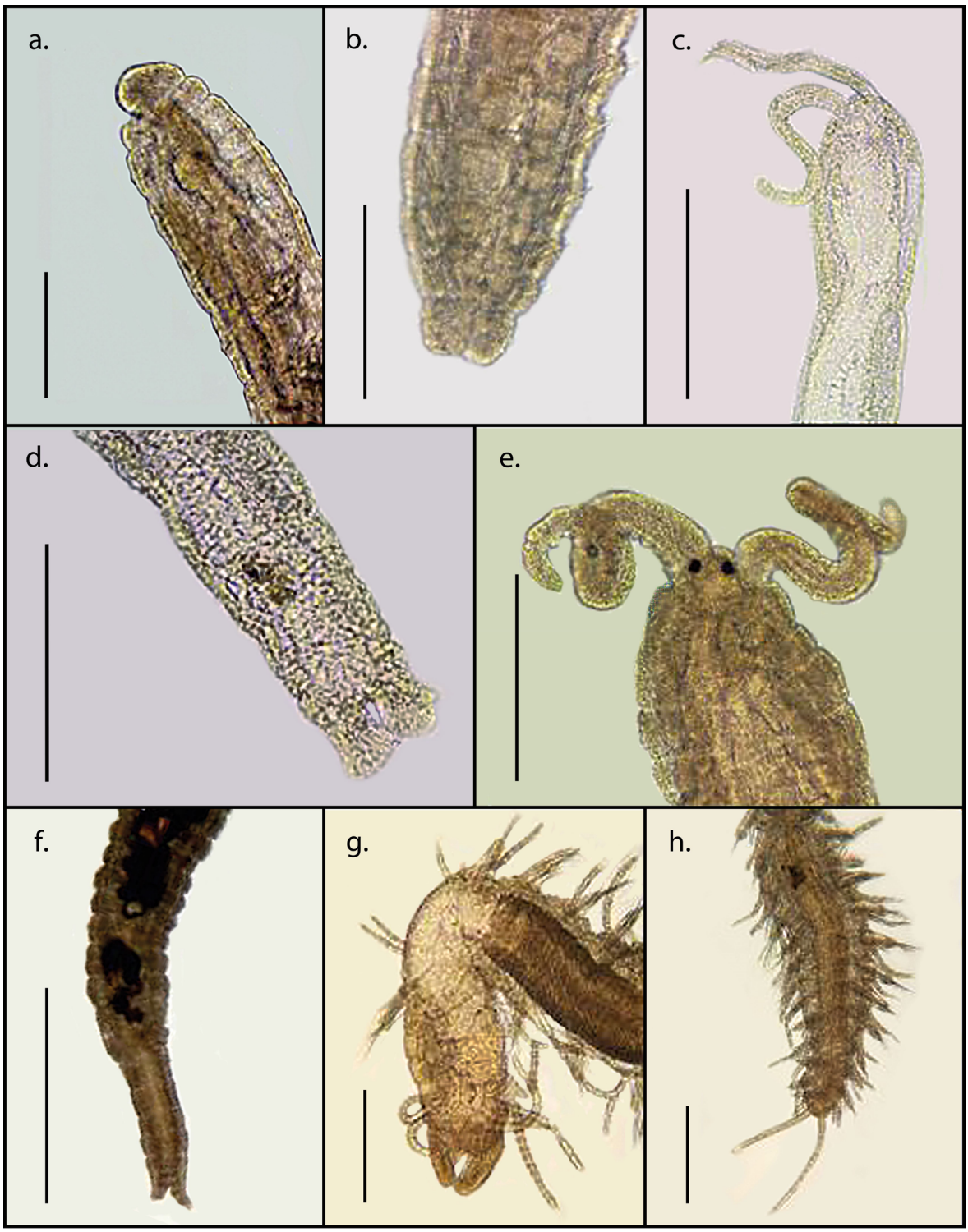

Figure 2. Organisms of the phylum Annelida, found in Johnny Cay Regional Natural Park. a-b. Enchytraeidae (100 µm), c-d. Protodriliidae (200 µm), e-f. Saccocirridae (100 µm), g-h. Syllidae (100 µm). Anterior regions: a, c, e, g. Posterior regions: b, d, f, h.

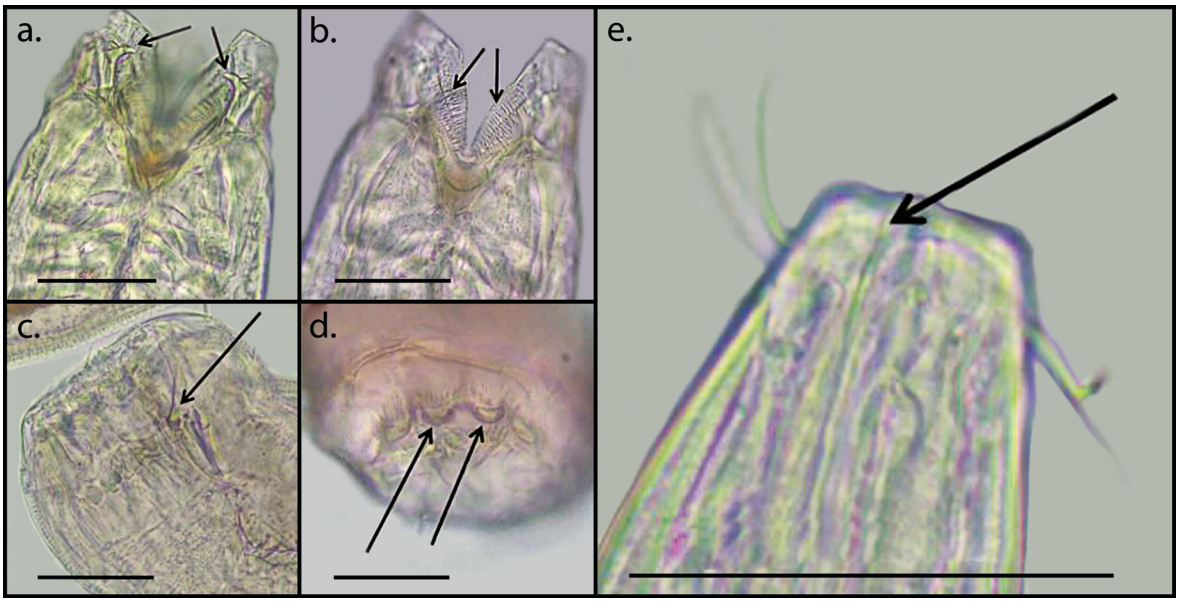

Figure 3. Organisms of the phylum Nematoda found in Johnny Cay Regional Natural Park. Head region of omnivores/predators, with a wide stoma and cuticularized mouth structures modified for predation. a. Thoracostomopsidae, b. Neotonchidae, c. Selachinematidae, d. Cyatholaimidae (Scales 30 µm (100×).

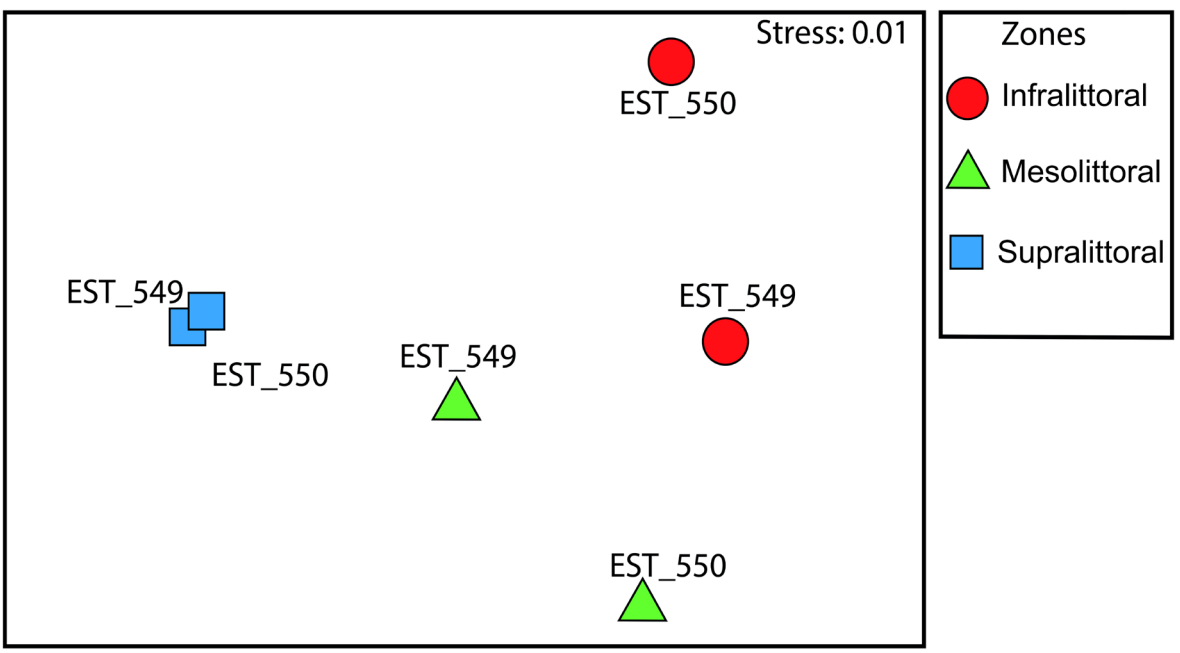

Figure 4. Non-parametric multidimensional scaling (nMDS) of the macrofaunal community found on the sandy beach of Johnny Cay, Colombian Insular Caribbean Region.

Table 2. Environmental variables measured on the sandy beach of Johnny Cay, Colombian Insular Caribbean Region.

Variables	EST_549			EST_550		
	infralittoral	mesolittoral	supralittoral	infralittoral	mesolittoral	supralittoral
Sediment temperature (˚C)	30.6	31.3	30.1	29.5	29.9	29.2
Carbonates (%)	83.89	89.55	88.50	98.36	81.69	69.63
Organic material (%)	3.30	3.40	2.70	3.30	3.40	3.30
Medium sands (%)	9.09	5.72	6.03	10.54	3.18	9.58
Coarse sands (%)	76.53	55.53	55.58	57.34	63.5	59.83
Very coarse sands (%)	13.84	36.79	36.80	31.31	33.12	29.48
Zone width (m)	9.30	11.00	13.40	4.10	17.50	28.00
*Water temperature (˚C)	30.6			29.5		
*Dissolved oxygen (mg/L)	5.60			5.84		
*Saturated oxygen (%)	93			99		

DISCUSSION

The macroinfaunal composition of Johnny Cay Island was strongly dominated by vermiform organisms, with annelids-oligochaetes being the most representative, followed by nematodes, with mollusks and crustaceans being represented by only a few organisms. These findings are consistent with a previous study conducted by INVEMAR in 2007, prior to the landing pier in the cay (INVEMAR, 2007), which has comparable proportions of the faunal groups observed in this study, emphasizing the absence of crustaceans and mollusks, despite their typical significance in benthic communities. It is important to highlight that the macrofaunal community composition of the study area could have been affected by the fixation with formalin solution with rose bengal, after narcotization with magnesium chloride, since soft-bodied organisms, such as flatworms and nemertines, may be affected by the treatment carried out, which implies a possible underestimation in the composition of the registered community; however, a large part of the benthic organisms that have been reported in this type of environments, are preserved well following this methodology.

This study reports for the first time the oligochaete families Naididae and Enchytraeidae inhabiting Colombian sandy beaches, and although this would be an expected result since they are common annelids of tropical beaches, in Colombia the study of the macrofauna on sandy shores is scarce, and among the existing ones, many remain as gray literature, partly due to the few resources allocated to its dissemination. Oligochaete organisms, in general are mostly terrestrial, and are little affected by the climate of the swept area in the marine environment, upper supralittoral regions, and high humidity is sufficient for them to survive (resistance to osmotic stress) (Defeo and McLachlan, 2005; Barboza et al., 2012); in this study, the Enchytraeidae family dominated in number of individuals the supralittoral of Johnny Cay, following the pattern previously described for these environments (McLachlan and Brown, 2006; Defeo and McLachlan, 2005), and the Naididae were found mainly in the mesolittoral and infralittoral zones. In general, all annelid taxa recorded at Johnny Cay are common inhabitants of beaches worldwide (Fauchald, 1973; Reis et al., 2000; Carcedo et al., 2015; Lagos et al., 2018).

Overall, nematodes were highly diverse and were most abundant in the infralittoral zone, where omnivorous and predatory trophic guilds (Wieser, 1953) were conspicuous, among other guilds; in contrast, in the mesolittoral and supralittoral zones, only omnivorous and predatory nematodes were reported. The prevalence of predators could be linked to the low percentage of organic matter in the area (Table 2) since organic matter deposition rates correlate with sand grain sizes on sandy shorelines (Gray, 1974). Reflective beaches, characterized by

high drainage rates and a concentration of coarse grains (mainly coral fragments), hinder organic matter accumulation in sediments, hindering the establishment of detritivores and filter-feeding species (Barboza et al., 2012).

Crustacean diversity was notably low in the infralittoral zone at one station, indicating a significant negative impact on the community, likely attributable to anthropogenic activities. This aligns with the adaptability of crustaceans in high human-impact areas, as highlighted by Cardoso et al. (2016). Individuals of the family Amphilochidae are amphipods commonly found associated with macroalgae and may also be tenants and commensals of sea fans, hydroids, and other sessile marine invertebrates (McKinney, 1978; Hoover and Bousfield, 2001; Leite, 2002), which explains the small number of individuals found specifically in the zone of marine terraces.

Concerning mollusks, they are prevalent invertebrates on sandy coasts, particularly adapted to the mesolittoral zone where they swiftly burrow for protection against drying. In Johnny Cay, mollusks were scantily documented, represented solely by a single *Echinolittorina* individual (Littorinidae family) in the infralittoral zone. This family, typically found on rocky coastlines, has been observed in high intertidal zones of beaches and mangroves (Ortiz and Blanco, 2012).

In the mesolittoral of Johnny Cay's sandy beach, the main changes in the community were observed: fewer faunal groups, low abundance of some, and dominance of others. The main hypothesis that explains the relationship between the macrofauna structure and the beach morphodynamics is known as the "Swash Exclusion Hypothesis" (SEH), which establishes the decrease in species richness, abundance, and biomass as a consequence of the increase in the strength of the swash zone, a steeper slope, and a thicker sediment, resulting in greater richness in dissipative beaches compared with reflective ones (Defeo et al., 2001).

Johnny Cay has proven to be a reflective-intermediate beach, presenting steep slopes and strong waves that transport sediment from the infralittoral to the mesolittoral zone and vice versa, with horizontal and vertical coastal drift movements thanks to the sediment pool to the south of the cay. According to the SEH, the feeding time of organisms on reflective beaches is generally reduced due to frequent washing (Barboza et al., 2012), making the mesolittoral zone the most changing strip of the beach, with a great exchange of materials (water, groundwater, marine spray and organic matter) both towards the supra and the infralittoral (McLachlan and Defeo, 2018).

The sandy coasts are heavily used and modified by human activities, potentially affecting the interstitial fauna, due to the negative impacts from unorganized recreational use (infrastructure construction, diving activities in shallow waters, boat rentals, collection of organisms for decorative purposes, sediment compaction due to heavy trampling and vehicle movement) (Saunders et al., 2000). In the San Andrés archipelago, a large part of the island population depends economically on its beaches for income and well-being; the Johnny Cay Regional Park has buildings and facilities for recreation and is visited daily by hundreds of tourists, thus trampling and other interventions, such as pollution (Garcés-Ordóñez et al., 2020a, 2020b), are considered to have negatively influenced the infaunal communities of the Cay.

The representative crustaceans of the beaches, such as decapods of the genus *Ocypode* and peracarids such as isopods – usually abundant, since they are groups with high tolerance and adaptations to highly morphodynamical environments (McLachlan and Brown, 2006; Torres, 2010) –, were not reported in this study. Some species of *Ocypode* with cosmopolitan distribution manifest predictable responses to human pressures, and thus, they are considered potential biological indicators of stressors such as trampling and vehicle traffic on beaches, which cause sediment compaction (Schlacher et al., 2010; Cardoso et al., 2016; Suciu et al., 2018). In this study, no decapods were observed, nor were there traces of burrows indicating their presence in the area, which can be explained by the high number of daily visitors to the cay, which may be compacting the sediment and, in turn, preventing these invertebrates from building their shelters.

The coastline of Johnny Cay has shown several changes in the last decade due to the strong hydrodynamics of the area, reporting three different main states of the beach or sediment transport in relation to the winds, including coastline retreats of the Cay to the East and small and narrow temporary beaches on the marine terraces area (Coca-Domínguez and Ricaurte-Villota, 2017). This coastal morphodynamics, together with the diverse landscapes that border the island seem appropriate to host a greater diversity of invertebrates on the JC sandy beach, since the connection between different habitats can also enable the arrival of new species. However, as was previously mentioned, environmental variables that allow us to better explain the community patterns need to be included in further research.

Consequently, further studies focused on knowledge of the sedimentary communities at Johnny Cay are needed to understand in more detail the functioning of the ecosystem and thus the role of species (such as *Ocypode quadrata*, or other bioindicator invertebrates) in this changing environment. Since the beaches also present physical and ecological links with dunes and subtidal ecosystems contiguous to the supratidal zone (Hesp, 2002; McLachlan and Defeo, 2018), which are also under anthropogenic pressures, future studies should include other physical parameters to be measured, such as sediment compaction, porosity, and permeability, which have been shown to be significant in the presence and/or absence of certain species (McLachlan and Brown, 2006). Undoubtedly, these tools will make a difference in proposing long-term monitoring of sandy beach fauna that will provide information to decision makers for the implementation of sustainable ecosystem management in areas such as Johnny Cay, highlighting the incredible ecosystem services provided by beaches and their vulnerability.

CONCLUSION

This work constitutes the first characterization of the macrofauna of the sandy coast of the Johnny Cay Regional Natural Park, relating its diversity to the morphodynamics of the beach. Its fauna was dominated by oligochaete worms (annelids) that present high resistance to osmotic stress. However, in terms of diversity, the absence of typical fauna beach groups such as crustaceans and mollusks prevailed, suggesting great anthropic disturbance by the constant people trampling, domestic animals, and vehicle traffic in the mid-and supralittoral zones, which highly affect the establishment of these groups by compacting the sediment. This raises the need to analyze the state of Johnny Cay sandy beach to optimize the provision of ecosystem services while maintaining ecological integrity.

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AUTHOR CONTRIBUTIONS

D.Y.G.: Conceptualization; Supervision; Investigation; Methodology; Data Curation; Analysis; Writing – Original Draft; Writing – Review & editing.

E.B-V.: Supervision; Investigation; Methodology; Analysis; Software; Writing – Original Draft; Writing – Review & editing.

C.A-F., M.A.M-M., B.M-C: Methodology; Investigation; Analysis; Writing – Original Draft; Writing – Review & editing.

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