

Macroinvertebrate-Derived Multimetric Indices and Physico-Chemical Water Attributes of a Sandy Coastal Ecosystem

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ABSTRACT

This study investigated the ecological status of the sandy coastal ecosystems of Riohacha, La Guajira. Using the bioindication capacities of the macroinvertebrates associated with the sandy substrates and the physicochemical attributes of the water. Three different beaches were delimited (A = Gubernation, B = Edifice Majayura and C = Centro Cultural), and sampling was carried out over a period of six months. To identify the macrofauna associated with the sandy substrate, the nucleator methodology was used, whereby it was integrated into the sediment of each specific beach region. For physicochemical attributes, assessments of pH, dissolved oxygen (DO), conductivity, salinity and temperature were carried out. revealed a 97 % correspondence for all beaches. Spearman's correlation between physicochemical parameters and the presence of organisms indicated a strong association with salinity (0.12), while the other parameters showed a significant inverse correlation. Margalef, Simpson and Shannon-Wiener diversity indices showed that the ecological conditions of beach B were better in relation to the other beaches, which can be attributed to a greater uniformity in the distribution of its species. The species that could be considered bioindicators of ecological quality on the beaches studied, because they show greater tolerance to fluctuations in the physico-chemical parameters evaluated, are *Arca zebra* and *Trachycardium muricatum*.

Keywords: biodiversity and conservation efforts, bioindication with macroinvertebrates, environmental conditions and diversity indices, ecological quality assessment.

INTRODUCTION

In coastal areas, macroinvertebrates alert the ecosystem to ecological and environmental conditions. The presence and abundance of macroinvertebrate organisms in intertidal zones reflects their quality. Their sensitivity to change makes them essential for the monitoring and management of coastal marine environments (Molina-Bolívar et al., 2020). Their use as bio-indicators aids decision-making in response to pollutants to improve environmental conditions. These species are key indicators of the ecological health of ecosystems due to their physical and chemical sensitivity to the environment. Their study provides information on

distribution, community structure and the impact they receive from salinity, temperature and organic matter content (Molina-Bolívar et al., 2018). In addition, their presence and diversity can indicate the level of contamination and ecological disturbance in the area. The mollusc *Donax denticulatus* in the monitoring of heavy metals on Colombian Caribbean beaches has reflected the deterioration produced by anthropogenic activities in these ecosystems (Valdelamar-Villegas & Olivero-Verbel, 2018). Riohacha beaches face significant environmental challenges, including the discharge of untreated sewage that has led to soil deterioration, destruction of intertidal flora and fauna, and increased health impacts on local communities (Herrera-Campuzano & Pacheco-Bustos, 2024).

Disturbances caused by heavy metals in coastal sediments are generally below critical contamination thresholds (Barros-Maestre & Granados-Martínez, 2016). These alterations pose a danger to benthic fauna and highlight the need for continued monitoring and management of these ecosystems to avoid further ecological deterioration (Doria Argumedo & Deluque Vilorio, 2015). The biodiversity of the Guajira peninsula, and specifically its integrity, is at risk from alterations in water quality (Vásquez-Carrillo & Sealey, 2021). This situation calls for activities that centre on management with the aim of achieving sustainable development and safeguarding these ecosystems. These concepts consider the origin of the sources that alter the ecosystem and improve the resilience of coastal zones to climatic fluctuations (Vásquez-Carrillo & Sealey, 2021). Monitoring of beach substrates is imperative for public health and ecological preservation of these systems (Vásquez-Carrillo & Sealey, 2021). It is important to bear in mind that these initiatives help to determine the elements that contaminate them (Chávez et al., 2018). It is important to note that innovations such as technological applications for water quality assessment, such as the ECAME software, streamline water quality assessment by combining various physical, chemical and biological parameters. This type of assessment strengthens actions aimed at the conservation of fauna and flora in marine, coastal and estuarine habitats (Jiménez-Pitre et al. (2018); Vásquez-Carrillo & Sealey (2021).

Although macroinvertebrates serve as bioindicators within a broader ecological framework, conservation initiatives, anthropogenic activities and natural phenomena must also be considered (Serna-Macias et al., 2023). This group of animals serve as the elements that assess the relationship with these communities, the application of technological applications has increased the effectiveness of monitoring and management approaches, thus ensuring the sustainable use of coastal resources (Rodrigues Capítulo et al., 2020). However, obstacles such as inadequate infrastructure and research prospects in the region require greater investment and collaboration to achieve efficient ecological management (Vásquez-Carrillo & Sealey (2021); Crespi-Abril et al. (2017). The coastal area of Riohacha is a critical ecosystem and the macroinvertebrates act as bioindicators of the environmental quality of the intertidal zone (Baquero Cárdenas et al., 2007). These organisms are sensitive to environmental disturbances and essential for monitoring and managing the ecological integrity of the coasts (Carrillo Beleño et al., 2020). Moreover, the use of this set of organisms has been shown to be an indicator that can facilitate rapid decision making in response to pollutants, reinforcing sustainable economic conservation efforts (Madera et al., 2016).

MATERIALS AND METHODS

This research was carried out in three sandy beach areas on the coast of Riohacha, La Guajira (Colombia), specifically at a latitude of 11°54'09.29'N and a longitude of 72°54'33.20' W. The climatic conditions of this region of the country are characterised by a xerophytic savannah to the south and west, while the northern and eastern sectors present a semi-arid climate, with a documented mean annual temperature of 28.3 °C, a rainy period from September to December and a dry period from May to August, together with a multi-annual relative humidity of 72 % (Molina-Bolívar & Jiménez-Pitre, 2020). The assessment of the ecological quality of the sandy coastal ecosystems of the study area was based on the methodological framework, which was characterised by the identification of three discrete sites (Herrera-Campuzano & Pacheco-Bustos (2024); Vásquez-Carrillo & Sealey (2021).

Figure 1 shows the sampling sites, namely beach A (Governorate), which is characterised by sparse vegetation and accumulation of organic matter. Beach B (Majayura Building) is characterised by limited human presence and disposal of anthropogenic organic waste to the southeast of the area, which contrasts with beach C (Cultural Centre). This area is characterised by an exceptionally low influx of visitors, offensive odours and disposal of anthropogenic organic waste, together with a proliferation of vegetation on the southern part of the beach. The nucleator, a cylindrical PVC tube inserted into the sandy substrate, had a

surface area of 18 cm² and was embedded at a depth of 15 cm into the sediment. Sampling was carried out monthly for six months between May and October 2023, comprising rainy and dry periods.



Figure 1. Field sampling sites in the study area (PA=G, PB=EM y PC=CC). Riohacha, La Guajira (Colombia).

To determine the biological species present, one sample per month was collected at each site for six months. Each individual sample was subjected to a filtration process using a sieve with an aperture of 0.5 mm, in order to separate the sediment from the biotic organisms and to quantify their density. These samples were then taken to the Biological Sciences laboratory of the University of La Guajira for further analysis. Live organisms and empty shells were taken to the laboratory for identification, stored in pre-labelled plastic bags and preserved in a 70% ethanol solution using a stereomicroscope and taxonomic keys. For their preservation, a 70% ethanol solution was used, after which they were taxonomically and systematically classified using a stereomicroscope and taxonomic keys (Díaz Merlano & Puyana Hegedus (1994); Fontalvo Palacio et al. (2010) ; Fernandes (2024). Dissolved oxygen concentration (mg/L), pH, salinity (UPS), conductivity and temperature (°C) were measured at each sampling site. To determine the structure of the organisms and were organised in electronic Excel® spreadsheets. The biological data were then validated using PAST 4.03 software (Hammer et al., 2001). Species richness (S), Shannon-Wiener (H'), Simpson (1-D) and Margalef indices were also calculated (Moreno, 2001). A summary statistic was then produced with the data derived from the above variables, incorporating the minimum, maximum, mean and standard deviation values for the different sites, all while using the same software to ensure consistency.

The Kruskal-Wallis H-test was then performed for the 18 samples (non-normality and homogeneity of variance) to determine whether or not there was any statistically significant difference in relation to each of the variables measured, such as the abundance of organisms and the physico-chemical parameters (Ostertagová et al., 2014). In addition, normality assumptions were tested using the Shapiro-Wilk test. Subsequently, a hierarchical cluster analysis was carried out, generating a matrix with the Bray-Curtis similarity index between the abundance of the macroinvertebrates and the physico-chemical variables (Ricotta & Podani, 2017). A Spearman correlation was then performed to measure the relationship between the variables and the organisms (Mendivelso, 2022).

RESULTS

A total of 557 specimens were assessed in detail from beach A, indicating a species richness (S) comprising 33 species, 2 classes (Gastropoda and Bivalvia) and 20 families. The species showing the highest abundance was *Ventricolaria listeroides*, classified within the class Bivalvia, with a representation of 87 individuals, constituting 15 % of the total catch. On the other hand, the species that showed the lowest abundance, with only one individual each (0.18 %), were *Oliva bewleyi*, *Oliva reticularis*, *Cypraea mus* and *Eudolium crosseanum*, from the class Gastropoda, as well as *Ventricolaria rigida*, from the class Bivalvia (table 1).

Table 1. Species richness and abundance encountered on Beach A (Governorate).

Class		Family	Species	Samples						Total
				1	2	3	4	5	6	
Gasteropoda	1	Turritelidae	1 <i>Turritella variegata</i>		1		2	2	2	7
	2	Calyptraeidea	2 <i>Crepidula convexa</i>		2				1	3
	3	Haminoeidae	3 <i>Atys riiseana</i>					1	1	2
	4	Marginellidae	4 <i>Pronum marginatum</i>					2		2
	5	Olividae	5 <i>Oliva bewleyi</i>					1		1
			6 <i>Oliva reticularis</i>						1	1
	6	Calyptraeidae	7 <i>Crucibulum auricola</i>					3	1	4
	7	Cypraeidae	8 <i>Cypraea mus</i>						1	1
	8	Cancellaridae	9 <i>Cancellaria reticulata</i>				1		1	2
	9	Tonnidae	10 <i>Eudolium crosseanum</i>				1			1
	10	Cerithiopsidae	11 <i>Bittium varium</i>						4	4
Bivalve	11	Mytilidae	12 <i>Brachidontes exustus</i>			2	5			7
	12	Crassatellidae	13 <i>Crassinella martinicensis</i>	7	2	2	16	14	6	47
			14 <i>Arca imbricata</i>	3	1	3	5	11	4	27
		Arcidae	15 <i>Arca zebra</i>	9	11	8	9	13	7	57
			16 <i>Anadara brasiliiana</i>	2	2	4	8	4	9	29
			17 <i>Anadara ovalis</i>	1	2	1	1	1	2	8
	14	Noetiidae	18 <i>Noetia bisulcata</i>	1	1		1		6	9
	15	Lucinidae	19 <i>Codakia costata</i>	1		1				2
			20 <i>Anodontia alba</i>		3	2				5
			21 <i>Ventricolaria rigida</i>		1					1
			22 <i>Chione subrastata</i>	1	2	1	2	1	2	9
			23 <i>Chione cancellata</i>		3	0	1			4
		Veneridae	24 <i>Pitar albidus</i>	6	7	4	10	10	4	41
			25 <i>Pitar arestus</i>	4	6	3	4	8	7	32
			26 <i>Tivela mactroides</i>		4	1	5		5	15
			27 <i>Ventricolaria listeroides</i>	20	8	10	10	18	21	87
			28 <i>Anomalocardia brasiliiana</i>			2	5	5	3	15
	17	Cardidae	29 <i>Trachycardium muricatum</i>	10	13	10	14	7	9	63
		Ungulinidae	30 <i>Diplodonta soror</i>	1			1			2
			31 <i>Diplodonta punctata</i>	3	9	5	4	2	2	25
	19	Donacidae	32 <i>Donax denticulatus</i>	2	4	1	2	5	1	15
	20	Ostreidae	33 <i>Crassostrea rhizophorae</i>	4	3	3	16		3	29
				75	85	63	123	108	103	557

The total number of species identified on beach B amounted to 27, classified in two different families: Gastropoda and Bivalvia. The cumulative count of individuals reached 268, belonging to 14 families; the species showing the highest abundance was *Arca zebra*, which accounted for a total of 29 individuals of the class Bivalvia, representing 10 % of the total sample. The species with the lowest abundance were *Crepidula convexa* and *Atys riiseana*, of the family Gastropoda, together with *Codakia costata* and *Ventricolaria rigida*, of the class Bivalvia, each with 0.37 %, equivalent to 1 individual recorded (table 2).

Tabla 2. Species richness and abundance encountered on Beach B (Majayura Boulding).

Class		Family	Species	Samples						Total
				1	2	3	4	5	6	
Gastropoda	1	Calyptraeidea	1	<i>Crepidula convexa</i>					1	1
	2	Haminoeidae	2	<i>Alys riiseana</i>					1	1
Bivalvia			3	<i>Arca imbricata</i>		3	1	1	2	7
			4	<i>Arca zebra</i>	4	6	5	6	3	29
	3	Arcidae	5	<i>Anadara brasiliiana</i>	2	5	5	1	1	20
			6	<i>Anadara ovalis</i>				1	1	3
	4	Noetiidae	7	<i>Noetia bisulcata</i>			1	1	1	3
			8	<i>Codakia costata</i>					1	1
	5	Lucinidae	9	<i>Anodontia alba</i>				2	1	4
	6	Mactridae	10	<i>Mulinia cleryana</i>	2	2	5	5	3	22
			11	<i>Ventricolaria rigida</i>					1	1
			12	<i>Ventricolaria listeroides</i>	3	2	2	3	5	15
			13	<i>Chione subrasta</i>	6	2	3		2	13
			14	<i>Chione cancellata</i>	2		2		2	6
	7	Veneridae	15	<i>Transenella cubaniana</i>	1		1	3	1	6
			16	<i>Pitar arestus</i>	1		3	3	1	13
			17	<i>Pitar albidus</i>			3		4	10
			18	<i>Anomalocardia brasiliiana</i>	1			3	1	5
			19	<i>Tivela mactroides</i>	1	2	1	1	2	13
	8	Cardidae	20	<i>Trachycardium muricatum</i>	1	1	4	9	4	25
	9	Ungulinidae	21	<i>Diplodonta soror</i>				2	2	4
			22	<i>Diplodonta punctata</i>	1				1	3
	10	Donacidae	23	<i>Donax denticulatus</i>	5	6	10	1	1	23
	11	Ostreidae	24	<i>Crassostrea rhizophorae</i>	2	3	4	3	1	14
	12	Crassatellidae	25	<i>Crassinella martinicensis</i>			2	3	1	10
	13	Mytilidae	26	<i>Brachidontes exustus</i>		1	1		1	3
	14	Turritelidae	27	<i>Turritella variegata</i>	4	4	5			13
				36	37	58	48	23	66	268

At beach C, 20 species were recorded, comprising 130 individuals, classified into 2 classes (Gasteropoda and Bivalvia) and represented by 9 families. The species with the highest presence was *Arca zebra* (Bivalvia), with a total of 45 individuals, which constitutes 34 % of the total abundance, while the species with the lowest abundance were *Crassinella martinicensis*, *Chione cancellata*, *Noetia bisulcata*, *Pitar dione* and *Diplodonta punctata*, from the Bivalvia class. In addition, *Cancellaria reticulata*, of the family Gasteropoda, was the only species of this class, represented by a solitary individual, accounting for 0.7% of the total population documented on this beach. The highest number of species (S) and individuals (N) was recorded on beach A, and the beach with the lowest record was beach C (table 3).

Table 3. Species richness and abundance encountered on Beach C (Cultural Centre).

Class		Family		Species	Samples						Total
					1	2	3	4	5	6	
Gastropoda	1	Cancellariidae	1	<i>Cancellaria reticulata</i>	1						1
	2	Cypraeidae	2	<i>Cypraea mus</i>				1	1		2
	3	Marginellidae	3	<i>Pronum marginatum</i>	1			2			3
			4	<i>Arca imbricata</i>	1	3	2	1		1	8
			5	<i>Arca zebra</i>	4	14	7	7	6	7	45
	4	Arcidae	6	<i>Anadara brasiliiana</i>	2	11	2	1		4	20
			7	<i>Anadara Ovalis</i>		3	2			1	6
			8	<i>Noetia bisulcata</i>	1						1
	5	Noetiidae	9	<i>Anodontia alba</i>		1		1			2
Bivalvia	6	Crassatellidae	10	<i>Crassinella martinicensis</i>		1					1
			11	<i>Ventricolaria listeroides</i>		1		1			2
			12	<i>Pitar albidus</i>		2					2
			13	<i>Chione cancellata</i>		1					1
	7	Veneridae	14	<i>Transenella cubaniana</i>		3		1			4
			15	<i>Pitar arestus</i>		2					2
			16	<i>Pitar dione</i>						1	1
			17	<i>Tivela mactroides</i>		5				1	6
	8	Cardidae	18	<i>Trachycardium muricatum</i>	2	6		1		1	10
			19	<i>Diplodonta punctata</i>	1						1
	9	Donacidae	20	<i>Donax denticulatus</i>	5	4	3				12
					18	57	16	16	7	16	130

Table 4 describes the statistics of the macroinvertebrates found on each of the beaches studied. It indicates the minimum number of individuals found and the maximum, average and standard deviation of the calculated data.

Table 4. Summary statistics of the macroinvertebrates found on the beaches (minimum, maximum, average and standard deviation).

	Beach A	Beach B	Beach C
Minimum-Maximum	87-557	29-268	45-130
Average	15,47	7,44	3,61
Standard Deviation	20,85	8,27	8,25

The results of the Shapiro-Wilk normality assessment revealed that the data set derived from the three coastal sites did not conform to a normal distribution ($P > 0.05$). The Kruskal-Wallis H-test revealed a statistically significant difference in sample medians ($P > 0.05$ and $P = 0.0002$). Hierarchical clustering analysis of invertebrates from each beach (A, B and C) shows the interrelationship between samples from these sites and results in four groups: The first group belongs to beach C (PC), comprising samples 1, 3, 4, 5 and 6 (M1, M3, M4, M5 and M6) with 50 % similarity. The second group comprises beach B, particularly sample 5 (PBM5), followed by all samples from beach A (PA), PBM4 and M5 together with PCM2, which has a similarity of 51 %; and finally, a group consisting of the remaining samples from beach B with a similarity of 68 % (figure 2).

For the study area, the Shannon-Wiener index (H') data ranged from 2.78 to 2.93 for beach A; for beach B, the values ranged from 2.87 to 3.02; and for beach C, the lowest values were recorded in the range of 2.11 to 2.45. Simpson's index (D) values ranged between 0.06 and 0.08 for beach A; between 0.05 and 0.07 for beach B, which represent the lowest values; and finally, the values for beach C, which ranged between 0.12 and 0.21, represent the highest dominance values. The Margalef index showed the highest value for species richness (5.06). For beach B a value of 4.65 was related and beach C had the lowest value compared to the other data (3.90). Figure 3A shows a trend of increasing oxygen saturation values on the three beaches during the months of March and April, in contrast to the dry season which starts with the third sampling in May and continues until August, when a marginal reduction is evident due to the increase in temperature.

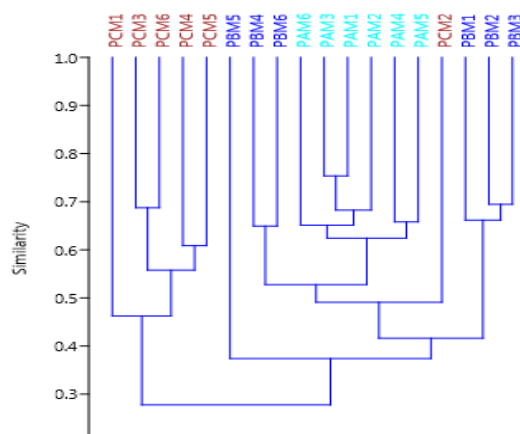


Figure 2. Cluster analysis by means of Bray-Curtis similarity between the abundance of macroinvertebrates sampled on each beach studied.

The highest oxygen saturation levels were documented at beaches A and B in sampling 2 in July, while at beach C they were recorded in May. The lowest levels were recorded in sampling number 6 in August for all beaches. The highest percentage was 87.1% (beach A), while the lowest was 77.9% (beach C). The data obtained for pH showed that the trend in each area is slightly basic, in a range between 8.21 and 8.31. Figure 8 depicts the lowest values for beach A, ranging from 8.21 to 8.26. The highest values were recorded for beach B, ranging from 8.27 to 8.31. However, a decrease in pH was observed for all beaches during sampling 3 (August), as shown in Figure 3B.

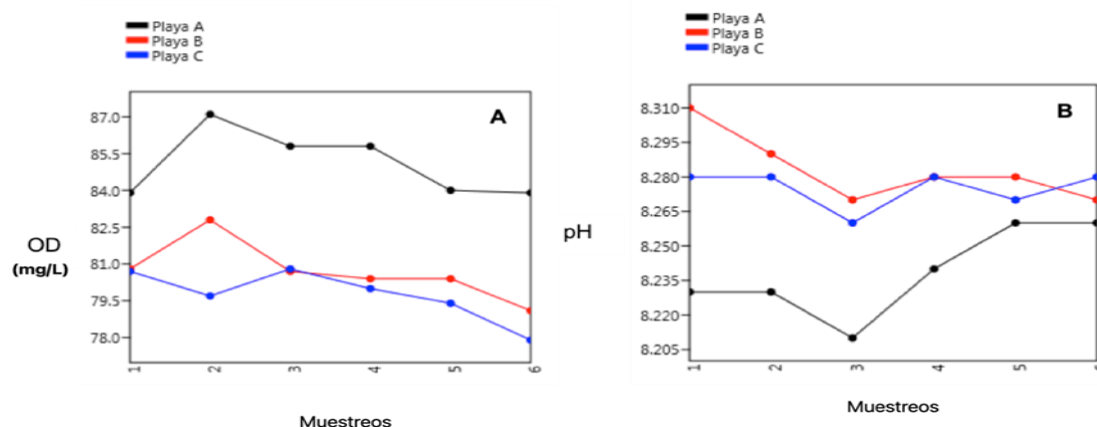


Figure 3. Description of the behaviour of DO saturation and pH on each of the beaches studied.

Temperatures at each beach range from 27.1°C to 29.7°C throughout the study area. The values for beaches B and C were found to be constant. However, beach C recorded the highest temperature values, unlike beach A, which had the lowest values, due to the fact that the solar intensity was lowest at the time of sampling (from 7:00 to 8:30) and gradually increased during the other sampling periods, ending at around 11:30 (Figure 4A). The highest salinity values were recorded at beach C, ranging from 35.3

to 37.3 UPS, and the lowest values were recorded at beach A, ranging from 35.3 to 37.1 UPS. The highest values were recorded during the third sampling, carried out from July to September, in contrast to sampling 1 and 2 (M1 and M2), carried out in May and June, where the lowest values were recorded (Figure 4B).

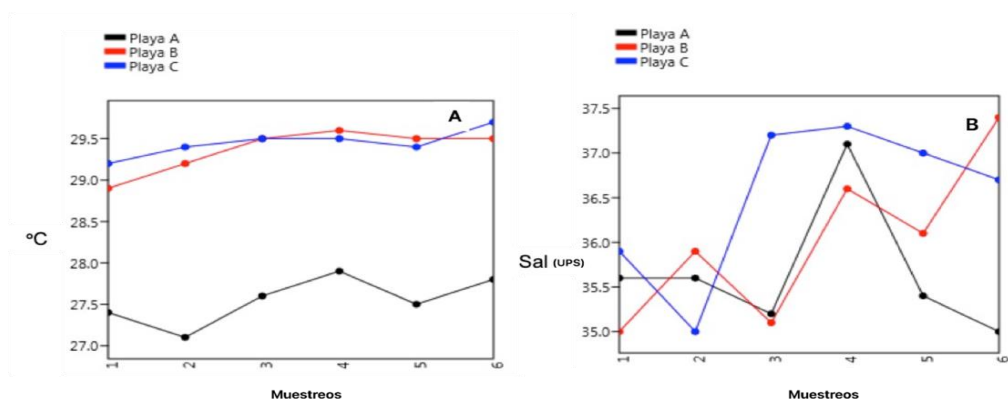


Figure 4. Behaviour of temperature and salinity in the studied beaches.

Figure 5 shows the lowest conductivity values in the first two samples from beaches A and C, while the lowest values for beach B were observed in the first and third samples. An increasing trend is observed towards the end of the dry season. The lowest value was at beach A with 52 mS/cm, and the highest at beach C with 58.8 mS/cm.

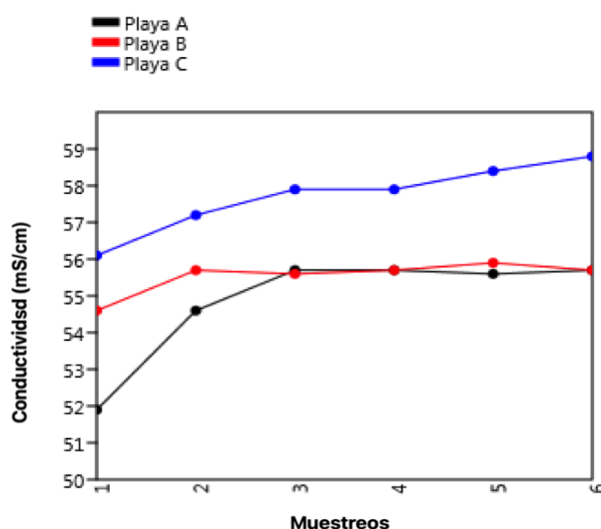


Figure 5. Conductivity behaviour on the beaches studied.

La tabla 5, describe los valores mínimos y máximos en los cuales oscilan cada una de los parámetros que se midieron en durante el presente estudio junto con el promedio y la desviación estándar.

Table 5. Descriptive statistics of the physico-chemical parameters for the whole study area.

	Temperatura	Salinidad	Conductividad	pH	OD %
Minimum - Maximum	27,1-29,7	35-37,4	51,9-58,8	8,21-8,31	77,9-87,1
Average	28,79	36,06	55,82	8,26	81,84
Standard Desviation	0,93	0,88	1,88	0,02	2,64

The Shapiro-Wilk normality test shows that there is no normal distribution ($p > 0.05$) between the data for temperature (0.001), salinity (0.04) and conductivity (0.03), unlike the rest of the variables. As for the Kruskal-Wallis H-test, it was determined that

there are significant differences between the physicochemical parameters of the samples from each beach ($p > 0.05$ and $p = 1.17 \times 10^{-17}$). The hierarchical cluster diagram (figure 6) shows the associations between the physicochemical variables on each beach, showing the formation of two large groups with a similarity of 97 %. The first group is formed by all the samples of the CP, including the M3, M4, M5 and M6 of the PB, with 98.8 % similarity, and the second group is formed by all the samples of the AP and the rest of the samples of the PB, with 98.2 % similarity. Translated with DeepL.com (free version) todos los muestreos de la PA y el resto de muestreos de la PB, con un 98,2 % de similitud.

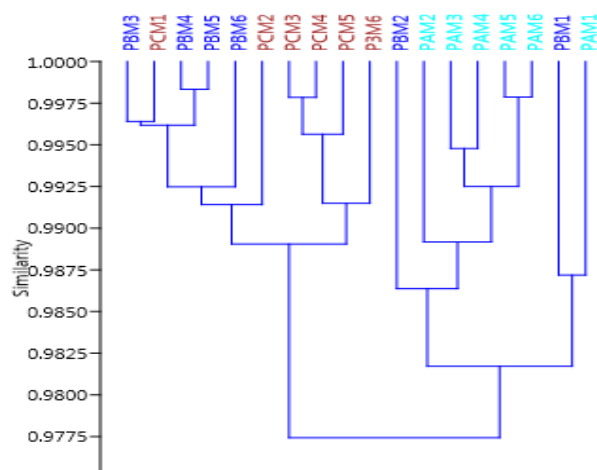


Figure 6. Cluster analysis by means of Bray-Curtis similarity between physicochemical variables.

To determine the ecological status of three beaches (A, B and C) in Riohacha, La Guajira, selected in this study, the variables of temperature, salinity, conductivity, pH and DO saturation were correlated with the abundance of macroinvertebrates in each sampling. A Bray-Curtis similarity clustering analysis was performed which, by means of a hierarchical cluster, showed the associations between the variables analysed, resulting in the formation of three groups: The first group was formed by PBM2 and almost all the CP samples, except for M2, with a similarity of 96.5 %; the second group was formed by PAM3, PCM2 and the rest of the CP samples, with a similarity of 94 %; and the third group was formed by almost all the remaining AP samples, with a similarity of 93.8 %. All beaches show a similarity of 87 % among the variables analysed (figure 7).

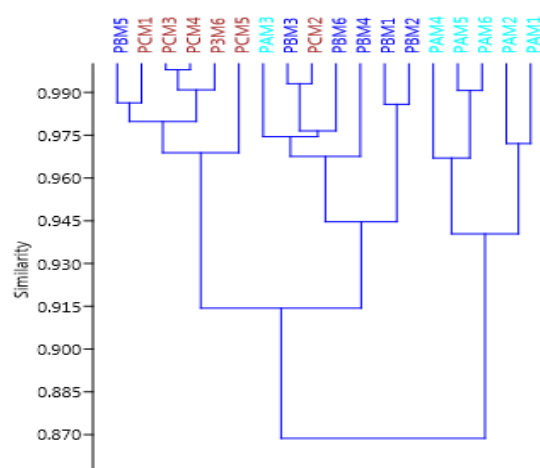


Figure 7. Cluster analysis by means of Bray-Curtis similarity between physicochemical variables and macroinvertebrate abundance in each sampling.

Subsequently, using Spearman's correlation coefficient (table 6), a significant correlation ($p > 0.05$) was determined between the abundance of organisms and salinity ($p = 0.12$), presenting a negative relationship. Values above the diagonal were determined as P values, while values below the diagonal were determined as r values.

Table 6. Spearman correlation coefficient between macroinvertebrate abundance and physico-chemical parameters.

	Abundancia	Temperatura	Salinidad	Conductividad	pH	OD %
Abundancia		0,004	0,12	0,02	0,01	0,002
Temperatura	-0,65		0,03	0,01	0,01	0,19
Salinidad	-0,38	0,51		0,07	0,91	0,11
Conductividad	-0,56	0,60	0,44		0,68	0,01
pH	-0,59	0,57	0,03	0,10		0,01
OD %	0,67	-0,83	-0,39	-0,60	-0,61	

DISCUSSION

The number of macroinvertebrates reported during the present study was 36 species with 955 individuals and 26 families distributed in two classes of the phylum Mollusca: Gastropoda and Bivalvia, the latter being the most abundant. In terms of the number of species, the study described by Rosado et al., (2006) in the same beach area, from the Valle de los Cangrejos to the Cultural Centre, was the same (36, S), but with a greater number of families (26), classes (8) and phylum (3). The beach with the highest number of species according to the Margalef index (5.06) was beach A (in front of the governorate), with 33 species and 557 individuals distributed in the two families. This beach is strongly influenced by the presence of people, which brings with it organic material deposited in the sediment, attracting those molluscs that feed on it and, therefore, causing the presence of more species in this area.

The beach with the highest diversity was beach B, which had the lowest dominance value (0.061) for Simpson's index and the highest value for Shannon-Wiener equity (2.96), resulting in a better spatio-temporal distribution and evenness of species in this area. However, the Margalef index was 4.65, making it the second with the highest number of species. Beach C (Cultural Centre) had the lowest species richness, with 20 species and 130 individuals. This beach had the highest dominance data according to Simpson's index, with a value of 0.17, compared to the rest of the beaches in the study. This caused the imbalance in evenness and, therefore, low species richness and equity, due to competition for space, food and other aspects essential for the survival of each community.

Of the organisms collected, the bivalves *Arca zebra* (131), *Ventricolaria listeroides* (104) and *Trachycardium muricatum* (98) were more abundant, because this class has a higher degree of tolerance, purification and accumulation of different degrees of pollutants (Acosta & Lodeiros, 2004). The most abundant species were Emerita sp. of the class Malacostraca, which was not found in this study, and Donax sp. of the class Bivalvia, as they withstand the changes that occur in the tide and waves, burying themselves in the sand (Rosado et al., 2006). On the other hand, the bivalve with the highest abundance was *Laevicardium sybariticum* (434), followed by *Euvola ziczac* (410), *Laevicardium pictum* (391) and *Arca zebra* (313), which means that the Bivalvia class is the most abundant on the beaches of Riohacha (Acosta & Lodeiros, 2004). The surveys with the highest number of species (26) were carried out during the dry season, from May to August. In contrast, the period of sporadic rainfall, from March to April, recorded only half of the species (12). This may be due to the strong influence of the Ranchería river mouth by sporadic rains, which have reached the sea (Molina-Bolívar & Jiménez-Pitre, 2020). Thanks to the exchange of polluting materials that are discharged into the river and washed out to sea, which accumulate in the sediment and in organisms, there is a loss of species richness and the proliferation of other more tolerant species (Acosta & Lodeiros, 2004). On the other hand, the clear decline of species on beach C may also be due to the discharge of wastewater, which has a considerable organic load and heavy metals (Doria Argumedo & Deluque Viloria, 2015).

Fluctuations in the physicochemical variables of the water determine the distribution and richness of species in the environment (García Padilla & Palacio, 2008). It is estimated that in the months of March and April, when the first two samples were taken, the ODA saturation percentages were the highest on all the beaches, thanks to the incidence of the sun, which decreases slightly and brings with it the trade winds (Molina-Bolívar & Jiménez-Pitre, 2020). Consequently, beach A was found to have the highest levels (87.1). The lowest DO saturation levels were recorded during the dry season, from May to August (M3, M4, M5 and M6), with the lowest values recorded for beach C (77.9 %), in front of the Cultural Centre. This decrease is due to the fact that a waste

effluent is located near this beach. This effluent may be the cause of the oxygen depletion, as it contains a considerable load of pollutants, including organic matter. For most of the data obtained for the physicochemical parameter pH, it was observed that the trend in each sampling area is slightly basic, with a range between 8.21 and 8.31. This value is within the standard values of the standards. This value is within the standards accepted by the Colombian legislation of Decree 1594 of 1984, which stipulates the permissible ranges in which estuarine and sea water must be. In the present study, it is observed that the lowest pH was obtained in M3 (month of May with 8.21 pH), where there were sporadic rains, which favours the decrease in the concentration of some basic compounds; and the highest, in M1 during the month of March, the pH was 8.31.

Salinity, conductivity and temperature behaved in a similar way. The lowest values were recorded in the first two samplings (M1 and M2) and, as the dry season progressed (M3, M4, M5 and M6), values increased until the last sampling in August, when the most abundant species on beaches A and B were: *Ventricolaria listeroides*, *Trachycardium muricatum* and *Arca zebra* on beach A; *Donax denticulatus*, *Arca zebra*, *Chione subrostrata* and *Turritella variegata* on beach B; and *Arca zebra*, *Anadara brasiliana* and *Donax denticulatus* on beach C. In the dry season, the most abundant species were, for beach A: *Ventricolaria listeroides*, *Trachycardium muricatum* and *Crassinella martinicensis*; for beach B: *Trachycardium muricatum*, *Arca zebra* and *Mulinia cleryana*; and for beach C: *Arca zebra*. The abundance of the species found in the study area is related to their wide distribution range, which makes them bioindicators of environmental conditions or pollution (Molina-Bolívar et al., 2024), (Rosado et al., 2006). The abundance of the Bivalve class has been found to be influenced by temperature and oxygen saturation, among other factors (Ríos-Jara et al., 2008). Beach C of the present study shows poverty and low diversity, due to alterations in environmental parameters essential for the survival of organisms. These changes are generated by the dumping of wastewater from domestic use and become tensors, as well as intervening in the ecological deterioration of the ecosystem (Cárdenas & Mair 2014); Baqueiro Cárdenas et al., 2007).

For the correlation analysis between the physic-chemical parameters of the water (temperature, salinity, conductivity, pH and DO saturation) and the abundance of macroinvertebrates found on all beaches, the Bray-Curtis similarity clustering analysis was used. In all cases, there was 87 % similarity between the variables analysed. The most similar beaches in terms of spatial and temporal and biological dynamics were PBM2 and PC (96.5 % similarity). With Spearman's correlation coefficient, a significant correlation was determined between the abundance of organisms and salinity ($p > 0.05$, where $p = 0.12$), it should be noted that the relationship between these variables was negative (Molina-Bolívar & Jiménez-Pitre, 2020).

CONCLUSIONS

Two types of macroinvertebrates of the phylum Mollusca were found during the study: Gastropoda, with 10 families and 11 species, where the most abundant was *Turritella variegata*; and Bivalvia, with 11 families and 23 species, where the most abundant were *Arca zebra* and *Trachycardium muricatum*. The Bivalvia class was the most abundant in the present study. Beach B had the best conditions and showed the best spatial-temporal distribution of species. Beach C showed a lower presence of macroinvertebrates, with a dominance and low species equity. Salinity, conductivity and temperature showed a relationship throughout the study. The first two samplings showed low values, and in the dry season, the number of species increased during the rainy period (March and April). In the dry season, *Arca zebra* increased, while *Trachycardium muricatum* was only recorded during the dry season. The pH and DO showed a similar and inverse behaviour in relation to salinity, conductivity and temperature; during the first two months of the study their values were high and during the drought they decreased. From the results obtained, it can be concluded that *Arca zebra* and *Trachycardium muricatum* are eurytopic species with high tolerance mechanisms to changes in the environment due to anthropogenic and natural activities. Therefore, the presence and abundance of these species is an indicator of the ecological quality of the beaches studied. The correlation between the physic-chemical parameters and the abundance of organisms and between beaches showed a similarity of 87 %. Spearman's correlation coefficient revealed a strong relationship between salinity and organisms on beach A, with representative values compared to the other beaches, with the exception of beach C, where the values showed scattered and independent relationships, being negative for all beaches.

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