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EDITORIAL

CIOH: 50 years of science and service to the sea

CIOH: 50 años de ciencia y servicio al mar

DOI: <https://doi.org/10.26640/22159045.2025.659>Alexis Grattz Bonilla¹

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The commemoration of the fiftieth anniversary of the Center for Oceanographic and Hydrographic Research of the Caribbean (CIOH) represents a milestone of huge significance for the country's maritime community. Since its creation in 1975 as a division of the General Maritime Directorate (Dimar), the CIOH has consolidated itself as an entity dedicated to generating knowledge on topics belonging to disciplines such as oceanography, hydrography, marine protection and the integrated management of coastal zones.

Five decades of uninterrupted work have allowed the CIOH to position itself as a national and international reference point for scientific research applied to the sea, making decisive contributions to maritime safety, the protection of human life at sea, and the preservation of marine and coastal ecosystems. Its contributions go beyond merely academic endeavours: they constitute a strategic pillar for how the Colombian Maritime Authority carries out its functions, showcasing the nation on the world stage.

The CIOH's track record is marked by both excellence and innovation. Over the years, its highly qualified human talent, with the support of scientific research platforms, has developed products and services that have had far-reaching impacts, such as the marine weather forecasts and the nautical cartography of Colombian territorial waters, both in the Caribbean and the Pacific. These contributions not only strengthen navigation safety, but also support decision making in strategic, economic and environmental settings.

In addition, I wish to highlight the role of the *CIOH Scientific Bulletin* as a tool for scientific dissemination since 1977. Its evolution as a unified journal shines a spotlight on the production of Dimar's research centers, located on the Caribbean and Pacific coasts. This issue of the Bulletin is a demonstration of how this publication contributes to preserving and promoting the scientific output of the CIOH.

The recognition of the scientific community and international bodies like the International Hydrographic Organization (IHO), the Intergovernmental Oceanographic Commission (UNESCO-IOC) and the World Meteorological Organization (WMO) reflects the robustness of our contributions. Furthermore, the endorsement of the Ministry of Science, Technology and Innovation (MinCiencias) in designating us as a recognised research center reaffirms the validity and relevance of our work, spurring us on to continue contributing knowledge that is both useful and applicable to the country.

Today the CIOH not only looks back with pride, but also maps out its future with renewed commitment. In a global context in which maritime safety, climate change and sustainable management of marine resources demand increasingly more comprehensive responses, the CIOH presents itself as an institution that is prepared for the challenges of the 21st century. Its capacity to integrate science, technology and public policy makes it a key player in ensuring a balance between development and sustainability in Colombia's maritime and coastal zones.

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Celebrating these 50 years means recognizing the value of those who have made this journey possible: the researchers, technicians and staff that have offered their knowledge and dedication to serve their country. It also means reaffirming our commitment to the coming generations, who will find the CIOH to be a strategic ally as they continue exploring, understanding and protecting marine heritage.

Our fiftieth anniversary is not the end of our journey, but rather a time to set sail again.

It is an opportunity to renew the scientific spirit, strengthen international cooperation and continue innovating for the benefit of the maritime and academic communities, and the whole of Colombian society. With a half century of experience and a forward-looking vision, the CIOH stands as a living testimony of what science can achieve when you combine a dedication to service and institutional commitment.

RESEARCH ARTICLE

Approach to the Patterns of Navigability, Accidentality and Sinking in Courtwon Cays: contributions to the Inventory of the Underwater Cultural Heritage of the Archipelago of San Andres, Providencia y Santa Catalina (Colombia)

Aproximación a los patrones de navegabilidad, accidentalidad y hundimiento en las Cayas del Este Sudeste: aportes para el inventario del patrimonio cultural sumergido del archipiélago de San Andrés, Providencia y Santa Catalina (Colombia)

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ABSTRACT

The development of interdisciplinary maritime and underwater archaeological research on Underwater Cultural Heritage in Colombian waters has seen considerable growth in recent years. In particular, studies in the Caribbean have been carried out not only off the coast of mainland Colombia but also around the Archipelago of San Andres, Providencia y Santa Catalina. We made scientific approaches there to inventory and characterize underwater cultural resources that can provide valuable historical and cultural information about the past of human societies. Under this premise, this article aims to present the interdisciplinary analyses made of Courtown Cays within the framework of the Seaflower Scientific Expedition during the year 2022, with the specific aim of understanding the patterns of navigability, accidents and sinkings in the region, in order to contribute to the national registry and inventory of the archipelago's Underwater Cultural Heritage. This was achieved by following the inter-institutional methodological proposals applied in recent years in different parts of the Colombian Caribbean.

KEYWORDS: Cultural Heritage, Accidents, Underwater Archaeology, Caribbean Sea, Colombia.

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RESUMEN

El desarrollo de las investigaciones de la arqueología marítima y subacuática interdisciplinaria sobre el patrimonio cultural sumergido depositado en aguas colombianas se ha visto expuesto a un crecimiento considerable en los años recientes. Particularmente, en el Caribe se han planteado estudios no solo hacia la porción continental de Colombia sino también hacia el archipiélago de San Andrés, Providencia y Santa Catalina. Allí se han adelantado aproximaciones científicas interesadas por inventariar y caracterizar los recursos culturales sumergidos que pueden brindar valiosa información histórica y cultural sobre el pasado de las sociedades humanas. Bajo esta premisa, el presente artículo pretende exponer los análisis interdisciplinarios planteados en islas Cayos del Este Sudeste, en el marco de la Expedición Científica Seaflower del año 2022, particularmente para comprender los patrones de navegabilidad, accidentalidad y hundimiento en la región, para así aportar al registro e inventario nacional de patrimonio cultural sumergido del Archipiélago. Lo anterior, aplicando propuestas metodológicas interinstitucionales aplicadas en los años recientes en distintas partes del Caribe colombiano.

PALABRAS CLAVE: *patrimonio cultural, accidentes, arqueología subacuática, mar Caribe, Colombia.*

INTRODUCTION

This research was part of the scientific expedition known as Seaflower: Isla Cayos de Bolívar 2022, organized by the Colombian Ocean Commission (CCO), which sought to contribute to the study of the submerged cultural heritage of Courtwon Cays, an area of the Caribbean that has been little analyzed from an archaeological and historical perspective (Del Cairo *et al.*, 2024a). To this end, the team proposed a working methodology that integrated the previous research perspectives used in the studies 'Patterns of navigability, accidents and shipwrecks in the Colombian Caribbean' (Del Cairo *et al.*, 2019; Del Cairo *et al.*, 2024b); 'Social appropriation of the maritime cultural landscape in Old Providence and Ketlina: characterization of the nautical space from a historical perspective' (Del Cairo *et al.*, 2020; 2022; Moreno & Báez, 2021), and 'Methodological proposal for registering Underwater Cultural Heritage assets in the bay of Cartagena de Indias and its surroundings' (Del Cairo *et al.*, 2021; Moreno, 2021).

To this end, the project brought together an interdisciplinary team of archaeologists, historians, conservators, oceanographers, hydrographers, technical divers, and social communicators to answer the research question: What natural and cultural elements have shaped

the historical maritime cultural landscape of Courtown Cays, and which areas have high potential for submerged cultural heritage? (Del Cairo *et al.*, 2024a).

Therefore, the overall objective of this study was to characterise the various components that make up the maritime cultural landscape of the area around Courtown Cays through a collaborative historical and archaeological approach (Del Cairo *et al.*, 2024a). For their part, the specific objectives were: to establish the relationship between the different human and non-human actors that shape the maritime cultural landscape in the Courtown Cays area; to determine the areas of high archaeological potential that are likely to be declared as assets and environments on the list of submerged cultural heritage from the 16th to the 20th century; and to establish mechanisms for community participation and the strengthening of local capacities in relation to submerged maritime cultural heritage (Del Cairo *et al.*, 2024a).

This article aims to show the preliminary results of the research, mainly in terms of methodological developments, the archaeological sites identified, and the community engagement outcomes as part of the project. In this way, it aims to provide an initial approach to the study of human interactions in the Colombian Caribbean cays throughout history.

STUDY AREA

The region of the Archipelago of San Andrés, Providencia and Santa Catalina is characterized by a series of oceanic islands, atolls and coral banks stretching in a north-easterly direction, which constitute the largest expanse of coral reefs in Colombia. Notable among these are the islands of San Andrés, Providencia and Santa Catalina, the shoals and banks of Quitasueño, Serrana, Alicia, Roncador and Bajo Nuevo, as well as Serranilla, Alburquerque and Courtown cays (Gamboa *et al.*, 2012). From an oceanographic perspective, the average sea surface temperatures around the archipelago vary between 26 and 29.5°C, with salinities below 35.5 and dissolved oxygen of around 6.4 mg/l in the surface layer (González & Hurtado, 2012).

Specifically, Bolívar Cay, also known as Courttown Cays or East Southeast Cays, is located 25 km southeast of the island of San Andrés,

separated from it by the Nutibara depression. The atoll is characterized by its kidney shape, and has a length of 11.7 km and a width of 5.1 km (Andrade-Amaya, 2010). One part has a SE-NW orientation and another is oriented NNW-SSE, and has three permanently emerged cays, although its shape has changed over the years. This atoll is surrounded by deep waters reaching 1,000 m in depth, and forms a lagoon with an opening to the west and southwest (Geister & Díaz, 2007). This atoll is made up of three cays: East Cay and Sand Cay, which currently form a single arch-shaped island; Middle Cay, which has disappeared; and West Cay, where the lighthouse and military post are located. The waves measured at the latter tend to come from an east northeast direction, so its west and southeast shores are the most sheltered (Andrade-Amaya, 2010). In addition, there is sediment, mainly sand and coral, although in some areas there are sediments with calcareous algae, rocky areas or seagrass vegetation (Geister & Díaz, 2007).

Location of the Bolívar Cay study area

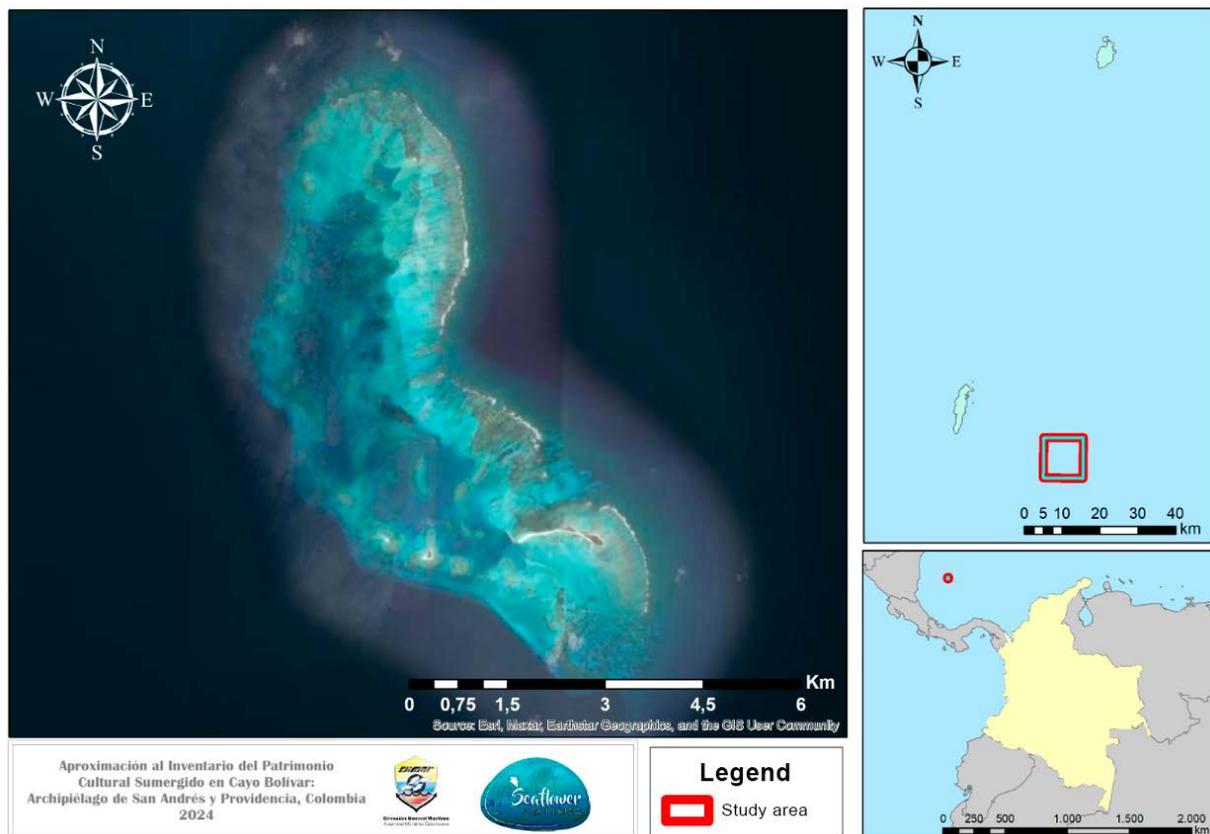


Figure 1. Location of the interdisciplinary archaeological study area around Courtown Cays.

METHODOLOGY

The methodology for this research was carried out in four phases. It was based on the theoretical and conceptual proposals for the maritime cultural landscape (Westerdahl, 2011; Duncan & Gibbs, 2015). This concept refers to all the constituent parts of the activities, objects and infrastructures related to the sea, which can be found both on land or in water (Westerdahl, 2011; Duncan & Gibbs, 2015). It therefore includes sailing routes, unoccupied spaces, landscapes of power and resistance, and sensory perceptions (sight, hearing and smell). The maritime cultural landscape also takes into account elements of landscape transformation such as technology, historical events, ecological change, complex social relations, gender differences, migration and associated cultural practices (Westerdahl, 2011; Duncan & Gibbs, 2015).

The methodology of this study included several components from the fields of archaeology, history and oceanography, among others (Fig. 2). Firstly, cartographic and historical documentary sources were compiled from national and international archives. Based on these, the aim was to identify patterns of navigation, accidents and shipwrecks, with an analysis of primary and secondary written sources as well as graphic sources (cartography and engravings), bearing in mind the proposal made by Del Cairo *et al.* (2019). To this aim, we carried out a discourse analysis —where possible— and a graphic analysis of the images, with the aim of determining oceanographic variables, changes in coastlines, navigation routes, possible locations of shipwrecks, landscape units, and toponymy and bathymetry, among other categories.

This methodology was complemented by the collection of oral sources, especially testimonies from co-researchers on the working team and local fishermen. In this regard, the aim was to construct a collaborative discussion of the phenomena of navigability and accidents, but also of the sinkings that occurred. Thus, through a co-participatory approach, the aim was to value the knowledge of local residents about past human relations with the sea.

Secondly, a field trip was made to carry out geophysical prospecting and collect field-based

oral testimonies. The prospecting was carried out using a Side Imaging Dual Beam echo sounder, which offers the possibility to map the seabed and identify anomalies in shallow water conditions. This was done taking into account that the study area has a large number of sandbanks and coral reefs that prevent the use of towed torpedo sensors (Del Cairo *et al.*, 2024a).

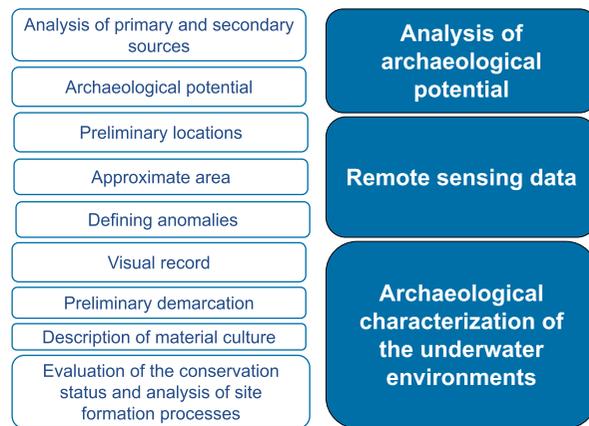


Figure 2. Obtaining interdisciplinary information from different information sources to carry out the different phases of the recording of the underwater cultural heritage landscape (Del Cairo *et al.*, 2021).

Thirdly, we attempted to strengthen local capacities in submerged cultural heritage, and maritime and underwater archaeology, aimed at students from the National University of Colombia-Caribbean Campus, thanks to the support of Professor Ana Isabel Márquez and the coordinating group of the CCO scientific expedition. This was due to the social and cultural nature of this research, which makes it essential to integrate and disseminate the research proposals and analytical perspectives put forward in this study in local communities. Finally, the information obtained from various sources, both at the office and in the field, was analysed and interpreted. These sources included historical cartography and engravings, oral tradition, raw sensor data, field findings, integration of local interpretative perspectives, and underwater and aerial audiovisual recordings, among others (Del Cairo *et al.*, 2024a) (Fig. 3).

RESULTS AND DISCUSSION

The configuration of the maritime cultural landscape of navigability and accidents in Bolívar Cay

The settlement of the Archipelago of San Andrés, Providencia and Santa Catalina may have begun in pre-Hispanic times, although evidence is limited. The Miskitos, settled around the Caribbean, may have used these islands for fishing and gathering (Márquez, 2014). The first written records date back to 1529 and Diego Ribero's map, reflecting the early importance of the area for navigation and that it attracted Dutch privateers and smugglers (Parsons, 1985). In the early 17th century, the English Company of Adventurers attempted to establish a colony on Providencia, highlighting its defensive value, and introduced slaves in 1633 to build public works. This happened after exploring Henrietta Island, which did not offer the necessary conditions for the colony (Parsons, 1985; Archibold Núñez, 2014).

Throughout the 17th century, there were conflicts to control the islands of the archipelago. One example of this is the capture of Old Providencia and Ketlina by the privateers Edward Mansfield and Henry Morgan. This marked a period of conflict between the Spanish and privateers for control of the territory, which even led to the destruction or reconstruction of the islands' fortifications (Rowland, 1935). Consequently, the landscape was transformed by the different power relations that were exercised on the islands.

Throughout the maritime territory of the archipelago, the waters not only became important for subsistence activities such as fishing, but also became strategic points for the navigation of ships from different European empires. The routes through the cays and islands served both as a reference for navigators and as a warning of the risks they posed. For example, Herrera and Tordesilla describes in detail the dangers and geographical characteristics of the region:

"and 5 leagues from that coast, the ants, a dangerous reef and at 7 leagues various islets surrounded by reefs, and to the south of them the Serrana and a small island surrounded by

shoals, with another four or five nearby, and to the northeast of it, La Serranilla and to the west, El Roncador, another shoal, and to the southwest of Santandres, an island surrounded by shoals, north-south, named after God, about forty leagues from it, and near there another called Santa Catalina" (De Herrera, 1601, p. 12).

The geographical complexity of certain areas of the Caribbean made the areas around these cays places that sailors preferred to avoid due to the high risk of being shipwrecked or getting lost at sea. For example, the area of Quitasueño and Roncador was described as: "two dangerous shoals and, following the Cape, the Gulf of Nicuesa where I got lost in 1510" (De Herrera, 1601, p. 56).

For this reason, the cays of the archipelago are frequently depicted in historical maps of this area. However, Bolívar Cay is not shown until the end of the 18th century, under the name "ESE Keys" (Fig. 3). This map shows the presence of boat traffic in the archipelago, especially in the area around the islands. Therefore, these boats would be found mainly to the northeast and east, given the typical Caribbean traffic both offshore and onshore.



Figure 3. Detail of the map "The Isthmus of Panama with the coast from Great River on the Moskito Shore to Cartagena", in which it is possible to see Bolívar Cay (ESE Keys) in 1775 (David Rumsey Historical Map Collection).

Another important event for the archipelago was the declaration of San Andrés as a minor port in 1798. This influenced sailing in the area by increasing the passage of legal and illegal commercial vessels. San Andrés thus functioned as a warehouse for English products awaiting

transport to the mainland, especially to places such as León in Nicaragua (Meisel-Roca, 2003; 2016; Parsons, 1985). Later, in 1803, the archipelago once again became subordinate to the port of Cartagena de Indias, marking a new commercial dynamic for the area (Parsons, 1985). At the beginning of the 19th century, the archipelago continued to be an important location for piracy and privateering. For this reason, there were still some privateer attacks and occupations, such as that of Captain John Bligh of the HMS *Surveillante* on the island of San Andrés in 1806 (Parsons, 1985).

Another important aspect in the history of the archipelago is its significance as a center for ships of the Colombian independence movement. In 1818, Luis Aury took over the islands of Providencia and Santa Catalina, making them one of the first settlements free from the control of the Spanish Crown (Cumming, 2017). However, after Aury's death, Louis Perú de Lacroix arrived to secure control and the island's support for Colombian independence, seeking to sign its accession to the Republic through the Constitution of Cúcuta. Following this event, it was established that the archipelago's government headquarters would be located on the island of San Andrés, under the command of Juan Bautista Faiquere. Thus, from 1822 to 1868, the province of Cartagena de Indias had the archipelago as its sixth canton.

At the same time, industry began to develop throughout the 19th century, which is another key element in understanding the different interactions of human beings with these maritime territories and the development of this maritime cultural landscape. For this reason, accurately locating the cays became a necessary activity. In this regard, in 1804 the Spanish mapped the area and, subsequently, HMS *Shearwater* made a correction, stating that the cay was further east, and established some bathymetric measurements with low accuracy (Gómez Pretel & Jeong, 2021). For example, the United States Hydrographic Service surveyed the area in 1885 and described Courtown Bank (with its Courtown Cays or E.S.E. cays, currently Bolívar Cay) as follows:

"This coral bank is irregular in shape and has a deep inlet on the east side. It is 7 miles long from NW to SSE, 1 to 2 miles wide, and its north and south ends terminate in points. Approximately

1 mile inside the northern point, a barrier reef convex to the northeast extends across the bank and along the eastern side for approximately 4 miles to the end of the curve, where it is very steep until it is beyond the range of soundings, barely a mile away" (United States. Hydrographic Office, 1885).

Thus, the trade in hawksbill sea turtles and turtle hunting became important, particularly in the northern cays (Parsons, 1985). For example, Roncador was a key point where boats of between 10 and 15 tonnes anchored in winter to "flip" the turtles on the beach and catch them with nets (Meisel-Roca, 2016; Parsons, 1985). These cays were frequently visited by fishermen from the Cayman Islands, who sometimes even spent a few days in the area (Parsons, 1985).

At the same time, the northern cays began to see significant guano extraction. This led to geopolitical problems with the United States, which had established the Guano Islands Act of 1856, which stipulated that US citizens could take possession of uninhabited islands that were not in the territorial waters of another country and that could be used for guano exploitation (Parsons, 1985). This is how James W. Jennett obtained a licence between 1868 and 1869 to exploit Serrano and adjacent cays, as well as Roncador, Quitasueño and Serranilla. Guano exploitation on the cays continued until the end of the 19th century, although they were never inhabited (Gómez Pretel & Jeong, 2021).

Similarly, on the other cays, the island government occasionally leased land to fishermen or turtle hunters, and even for the cultivation of coconut palms. Edward Blunt (1867), in the twenty-first edition of the *American Coast Pilot*, a publication that had been in production since 1796, also mentions that Bolívar Cay is made up of three small cays, composed of sand and coral stones, which have different types of vegetation, including coconut trees:

"The most easterly is one mile away from the shoal and two miles from the southern end; it is a quarter of a mile long and a cable length wide, is four feet above sea level, and is covered with dwarf bushes and cacti. The middle cay is located one and a half miles to the south west; it is six feet high and in addition to shrubs has a

grove of coconut trees. This cay is located at lat 120 24 N long 81 28 27 W, and lies sixteen miles SE from the southern tip of San Andrés. The western islet lies four cable lengths NW from the middle Cay and about the same distance from the limit of the soundings. It is very small and low and covered with dwarf bushes. One and a quarter miles WNW from the easternmost of the aforementioned Cays there is a small dry sand hole” (Blunt, 1867).

Bolívar Cay has also been an important point for navigation, especially due to its proximity to the larger islands in the area. Thus, it “has traditionally helped the navigation of cabotage schooners arriving in San Andrés from the south” (Parsons, 1985). Reports for navigators mention that it is possible to anchor at the edge of the Courtown Bank, although precautions must be taken to “not lower more than one cable” (Blunt, 1867).

For these reasons, resources such as water supplies were an important factor for ships. In this regard, Blunt (1867) mentions that it is possible to obtain water by digging wells, especially in the central and eastern cays. These characteristics made the cays a destination for fishermen and turtle hunters, who set up “temporary huts [...] during the turtle fishing months, from March to August” (Blunt, 1867).

Due to geographical conditions, the cay area of the archipelago was the site of many accidents. Between the 1950s and 2012, there were tropical and extratropical storms near Bolívar Cay, especially to the east of the cay, as well as a hurricane in the south of the study area (González & Hurtado, 2012). On a larger scale, Gómez Pretel & Jeong (2021) identified 36 hurricanes that affected, among others, the Roncador, Serranilla, Bajo Nuevo, and Serrana cays, as well as the shipping routes to Honduras, Cartagena, and Nicaragua. In addition, there were 23 shipwrecks that are possibly located near the Roncador Cays Islands, based on an analysis of the period between 1531 and 1920. However, it should be noted that the number of accidents identified as being caused by hurricanes was relatively low, so there is no clear correlation between these factors and the accident rate in the area (Gómez Pretel & Jeong, 2021).

In particular, it is worth highlighting some sinkings and accidents that occurred in the vicinity of Bolívar Cay, especially towards the southeast. The first was the HMS Wolverine, which sank on 11 August 1855 in the southeast part of Courtown Bank, off the Mosquito coast, 160 miles from Greytown. This vessel, built in 1836, was a 428-ton brig sloop measuring 101x32 ½ feet. Its commander was John Corbett, from North America and the West Indies, and its entire crew was saved (Colledge & Warlow, 2010; Maritime Archaeological Sea Trust, 2017). Similarly, the Tyne Built Ships website mentions that the cargo ship called ‘Energía’ was wrecked in the Courtown Cays, off the coast of Nicaragua, in 1918. This ship had been built by the Tyne Iron Shipbuilding Company at Willington Quay in 1883. It was a metal vessel with the following dimensions: 3177 GRT, 2064 NRT, 337.0 x 41.2 x 26.5 feet (Robinson & Wall, n. d.). However, no archaeological evidence of this vessel has yet been found.

Similarly, in 1938, there was an accident involving the Norwegian freighter Newsome, which ran aground off Courtown Keys, 225 miles northwest of Panama. However, it was rescued by the United Fruit ocean liner Veragua. The Newsome weighed 1,605 tonnes and was carrying ballast cargo (Lloyd’s Register Foundation, 1838; The New York Times, 1938). Later, in 1964, the frigate Almirante Padilla sank while en route to San Andrés. This vessel ran aground on the coral reef on the western side of Bolívar Cay. However, due to the strong waves and despite the arrival of two vessels (Antioquia and Pedro de Heredia) and, later, a US vessel (US County) to tow it, it was concluded that the maneuver was too dangerous. The ship was abandoned and then blown up with explosives so that it would not remain in sight (Caro Triana, 2012).

Historical sources show that sailing in the cay areas, particularly around Bolívar Cay, was strongly influenced by its proximity to San Andrés, so the ships that sailed there may have been searching for this piece of land. Additionally, it was observed that the southern part of the cay might be highly accident-prone due to environmental conditions (the direction of currents, the presence of hurricanes and tropical storms), which coincides with the

presence there of some shipwrecks such as the aforementioned Wolverine. Oral sources also identified areas with the possible existence of submerged archaeological sites and areas whose environmental conditions made navigation difficult, which could be of great importance for the study of accidents in the area.

Characterisation of areas of high archaeological potential associated with local underwater cultural heritage

Taking into account the historical information gathered, oral sources, and the different

oceanographic and hydrographic characteristics of the area, we identified certain areas of archaeological potential that could be linked to navigability or accidents. Consequently, a geophysical survey was carried out using a Side Imaging Dual Beam Sonar (Humminbird Helix 15) (Fig. 4) in the vicinity of the coral reefs. This was done based on the hypothesis that these areas could present a greater risk to navigation and, therefore, may constitute an area with a high accident rate. A total of four (4) areas of interest were reviewed, two (2) of which were associated with anomalies, and six (6) visual verifications were carried out by snorkelling and scuba dive.

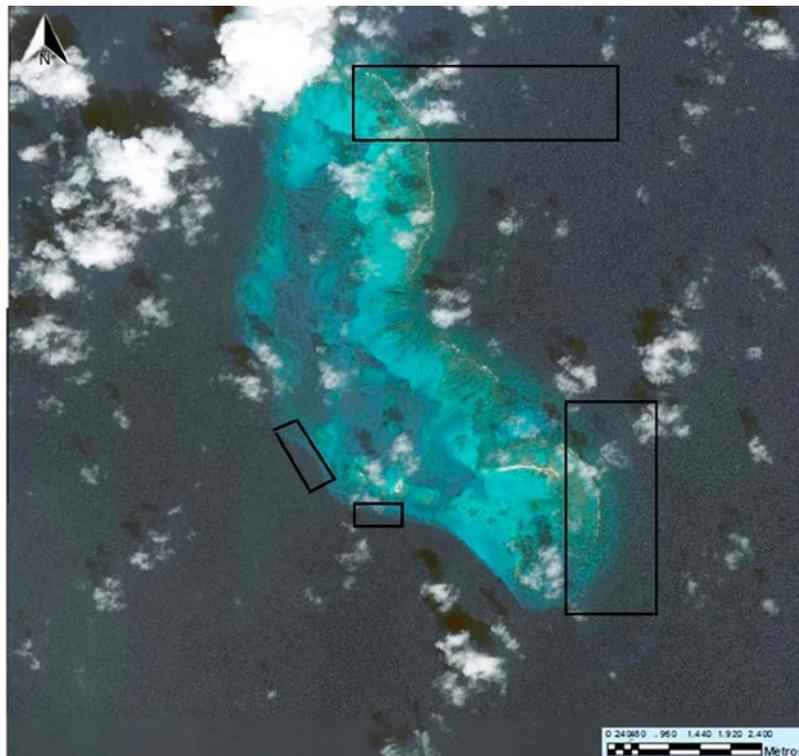


Figure 4. Areas surveyed during the field work.

Later, with the sonar data obtained during the field trip, raw data post-processing was carried out in the office using ReefMaster software to identify possible anomalies of archaeological interest and characterize the sites identified, to be subsequently corroborated *in situ*.

During two of the visual inspections, the team found two shipwrecks at shallow depths. The team and members of the expedition carried out a couple of SCUBA dives there with the aim of

obtaining a photographic and film record of the site for subsequent analysis in the office, which would allow it to be studied in greater detail and hopefully determine its spatio-temporal origin, eventually allowing for its possible identification.

“Lampa” Wrecksite

During the first visual inspection of one of the sites, an iron vessel measuring almost 70 m in length and 10 m in beam was identified, which we

named the “Lampa” Site (after the captain of the boat, navigator, diver and fisherman who allowed us to access to the site: Peter Betancur), which had multiple pieces of evidence throughout the site, including the possible engine, a structure, possibly from the bow, and structural elements yet to be identified (Figs. 5 and 6).

Given its characteristics, it is possible that this wreck is that of the Colombian Navy frigate ARC Almirante Padilla, a vessel originally from the United States that served in the Second World War and was later acquired by Colombia, and also participated in the Korean War. In the 1950s or 1960s, it was dynamited near Bolívar Cay (Ardila Pinilla, 1964) (Fig.), probably leaving the artefactual evidence seen today.



Figure 5. Underwater photographic record of the “Lampa” wrecksite (Photo: Santiago Estrada-Dimar).

“San-Thiago” wrecksite

At another site, a shipwrecked vessel approximately 50 m long and 15 m wide was found, which we named the “San-Thiago” site (also associated with the boat captain, navigator, diver and fisherman who observed it exposed in the distance: Santiago Arango). As at the previous site, large iron objects can be seen throughout the entire site; however, in this case, evidence suggests a greater age than the “Lampa” shipwreck (approximately the late 19th and early 20th centuries).

The site contains part of the engine room, two well-preserved boilers, a complete propeller, structures associated with the hull of the vessel (which delimit the outline of the site in the shape of the bow of a possibly steam-powered ship), the helm, a windlass, the stern fin where a propeller was attached with several blades missing, two anchors with their chains deployed, an isolated anchor of a different type, as well as multiple and diverse structures that are yet to be identified. Despite all this information, the possible identity of the ship has not yet been determined.



Figure 6. Underwater photographic record of the "San-Thiago" wrecksite (Photo: Santiago Estrada-Dimar).

Local capacity-building workshops

During the field season, outreach activities were carried out with students from the National University of Colombia-Caribbean Campus, with the aim of strengthening local capacities in underwater cultural heritage and maritime and underwater archaeology. The students came from programmes such as Anthropology, Sociology, Social Work, Law, Nutrition, Electrical Engineering and Nursing. On the one hand, a workshop was held at the University to familiarize students with the topics of study and the disciplines that made up the project. Topics such as the following were addressed: a) research objectives; b) study methodology; c) technologies to be implemented; d) basic principles and concepts of archaeology and cultural heritage; e) the universe and diversity of submerged cultural heritage.

On the other hand, a second session was held at Bolívar Cay, addressing in this case the progress

of research within the framework of the entire expedition. In particular, this project addressed several topics, including: a) a summary of the introductory session; b) the general questions that guided the development of field activities, such as what happened at Courtown Cays in the past? and what is its place in the history of the Archipelago?; c) the corroboration of the existence not only of patterns of navigability and accidents, but also of corroborated shipwrecks around the cay (given the presence of submerged archaeological finds); d) presentations by the two boat captains who located the sites (namely, Peter "Lampa" Betancur and Santiago "Tiago" Arango) and their description of the research methodology, methods and techniques implemented, the discovery of the two shipwrecks, the possible causes of their sinking, and the possible past navigational occurrences that may have occurred around the island based on environmental factors and Caribbean naval traffic in recent centuries; e) the presentation of the first underwater and

aerial photographs (courtesy of Santiago Estrada and Esteban Herrera) of the two main sites for the young students to see; f) the recognition of these sites as possible historical shipwrecks given the presence of materials, the distribution and dispersion of the objects, and the evidence of the sinking event. In short, the aim was to discuss and present the different skills taught, the principles of maritime and underwater archaeology, as well as the techniques, methods, methodologies and technologies of recording and documentation.

CONCLUSIONS

Throughout the research, it was possible to study the components that make up the maritime cultural landscape of the Archipelago of San Andrés, Providencia and Santa Catalina, with a particular focus on Courtwon Cays. These cays have historically been strategic for both navigation and the extraction of natural resources, but they are also dangerous due to complex environmental conditions that make maritime maneuvers difficult. Based on primary sources, it was possible to identify some areas (especially to the south and southeast) where there is a greater possibility of accidents or shipwrecks.

During the field trip, it was possible to identify two archaeological shipwreck sites around Bolívar Cay. Although this research has focused on the initial identification and documentation of these sites, we recommend that more detailed studies be carried out to gain a more accurate understanding of the causes of the sinkings and their historical context. Therefore, the recognition of these sites is a first step toward supplementing the national registry of underwater cultural heritage in the island areas of the Colombian Caribbean.

The participation of local communities has been key to carrying out the research, integrating their knowledge with interdisciplinary and community-based maritime archaeology, under in their role as of co-researchers. Activities with the region's inhabitants have made it possible to generate a broader interpretative framework for the phenomena related to sailing in this area.

In addition, interaction with the various local actors involved in the scientific expedition revealed concern about the vulnerability of underwater cultural heritage, especially due to looting and

the illegal extraction of artefacts. The public imagination of underwater heritage being linked to 'treasures' and goods that could be sold as antiques has led to these sites of common interest being subject to looting and illegal extraction of artefacts, resulting in the loss of valuable historical and cultural information that can help in understanding the past. For this reason, it is essential to create spaces for the appreciation and ownership of these archaeological elements aimed at those who are in the Courtwon Cays area on a daily basis (fishermen, sailors, divers, boatmen, etc.).

This shared history can be interpreted and studied in greater depth if the archaeological sites continue, as far as possible, to be preserved as they have been until now. Consequently, we also propose that a space for dialogue be created with the Bolívar Cay military post (in coordination with the Port Authority of San Andrés), so that military personnel on duty in the area for surveillance purposes can learn about the existence of these sites and recognize the cultural potential of the region. All this is intended to contribute to the long-term surveillance, control, security and monitoring of the sites, preventing their irreparable loss to possible looting.

Finally, it is crucial to implement conservation measures for the underwater archaeological sites around Courtwon Cays, not only because of their historical value, but also because of their role in marine biodiversity. To this end, it will be necessary to connect the inter-institutional and inter-sectoral competences of each of the entities responsible for the protection of these assets and the natural environments that surround them, recognising their interdependence.

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AUTHORS’ CONTRIBUTIONS

Conceptualization, C.D.C.H., J.A.A.M., M.M.C., L.V.B.S., J.C.J., G.L.H., C.R.A., A.C.S., L.L.B.T.; methodology, C. D.C.H., J.A.A.M., M.M.C., L.V.B.S., J.C.J., G.L.H., C.R.A., A.C.S., L.L.B.T.; software, J.A.A.M.; analysis and research, C. D.C.H., J.A.A.M., M.M.C., L.V.B.S., C.R.A., L.L.B.T. J.C.J.; resources, A.C.S., M.M.C., G.L.H.; data curation, C. D.C.H., J.A.A.M., M.M.C., L.V.B.S., C.R.A., L.L.B.T. J.C.J.; writing – original draft, C.D.C.H., J.A.A.M.; writing – review & editing, C.D.C.H., J.A.A.M., L.V.B.S.; visualization, C.D.C.H., J.A.A.M., L.V.B.S.; supervision, A.C.S., M.M.C., G.L.H.; project administration, A.C.S., M.M.C., G.L.H.; funding acquisition, A.C.S., M.M.C., G.L.H. All the authors have read and accepted the published version of the manuscript.

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RESEARCH ARTICLE

Detection of pathogenic microorganisms in ballast water of internationally trafficked vessels that arrived at maritime ports on the Colombian Atlantic coast during the years 2020 to 2023

Detección de microorganismos patógenos en agua de lastre de buques de tráfico internacional que arribaron a puertos marítimos de la costa Atlántica colombiana durante los años 2020 a 2023

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ABSTRACT

Ballast water has historically been used in vessels to maintain their stability during a voyage. However, this practice posed a significant environmental risk, as it facilitated the transport of marine organisms from one ecosystem to another. To mitigate this impact, international regulations were implemented, including the D-2 standard established by the International Maritime Organization (IMO), which requires the reduction or elimination of living organisms through onboard treatment systems. In this context, the present study aimed to detect pathogens in the ballast water of ships in Colombian seaports, to verify compliance with Resolution 477 of 2012 issued by the General Maritime Directorate (DIMAR). The study included vessels that arrived at various Colombian seaports. The methodology used was to take samples directly from the ballast water tanks in order to detect indicator microorganisms defined by the D-2 standard, specifically *Vibrio cholerae*, *Escherichia coli* (E. coli) and intestinal enterococci, as well as the study of ship registry documentation to counterbalance the validity of the research. The results showed that *Vibrio cholerae* presented a concentration of <1 colony-forming unit (CFU) per 100 ml in all monitored years (2020 to 2023). In the case of E. coli, growth was evidenced in one ballast water tank in the year 2023; however, the values remained within the permissible limits established by the regulation. For its part, there was growth of intestinal enterococci exceeding the 100 CFU/100 ml limit stipulated by the D-2 standard in two sampled ships, in the years 2020 and 2023. In the same way, the vessels comply with the records updated to the date of the implementation of the treatment systems. This study reinforces the importance of having regulations that allow for comprehensive management of environmental sustainability in the oceans, and that, when regulated, monitoring is continuous.

KEYWORDS: Ballast water, ship, water filtration, microorganism, ports, maritime transport.

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RESUMEN

El agua de lastre fue utilizada históricamente en las embarcaciones para mantener su estabilidad durante la navegación. Sin embargo, esta práctica representó un riesgo ambiental significativo, ya que facilitó el transporte de organismos marinos de un ecosistema a otro. Para mitigar este impacto, se implementaron regulaciones internacionales, entre ellas la norma D-2, establecida por la Organización Marítima Internacional (OMI), la cual exige la reducción o eliminación de organismos vivos mediante sistemas de tratamiento a bordo de los buques. En este contexto, el presente estudio tuvo como objetivo realizar la detección de patógenos del agua de lastre en puertos marítimos colombianos, con la finalidad de verificar el cumplimiento de la Resolución 477 de 2012, emitida por la Dirección General Marítima (Dimar). El área de estudio incluyó los buques que arribaron a diversos puertos marítimos de Colombia. La metodología empleada fue la toma de muestras directamente de los tanques de agua de lastre para la detección de microorganismos indicadores definidos por la norma D-2, específicamente *Vibrio cholerae*, *Escherichia coli* (*E. coli*) y enterococos intestinales, así mismo el estudio de la documentación de registros de buques para contrarrestar la validez de la investigación. Los resultados mostraron que *Vibrio cholerae* presentó una concentración <1 unidad formadora de colonia (UFC) por 100 ml en todos los años monitoreados (2020 a 2023). En el caso de *E. coli*, se evidenció crecimiento en un tanque de agua de lastre en el año 2023; no obstante, los valores se mantuvieron dentro de los límites permisibles establecidos por la normativa. Por su parte enterococos intestinales mostró un crecimiento superior a 100 UFC/100 ml en dos buques muestreados durante los años 2020 y 2023, superando los valores estipulados por la norma D-2. De igual manera, los buques cumplen con los registros al día de la implementación de los sistemas de tratamiento. El estudio realizado refuerza la importancia de la existencia de normativas que permitan una gestión integral de la sostenibilidad ambiental en los océanos, y que al estar regulada el seguimiento es continuo.

PALABRAS CLAVE: agua de lastre, buque, filtración de agua, microorganismo, puerto, transporte marítimo.

INTRODUCTION

International maritime transport is the backbone of global trade, moving around 80% of the world's traded goods (UNCTAD, 2017; 2023). However, this activity, which is essential to the global economy, faces significant environmental challenges that require an urgent transition to more sustainable operating models. Among these challenges, one of the most critical, yet least recognized, is the uncontrolled discharge of ballast water by international vessels: a routine process that, paradoxically, threatens marine biodiversity and human health on a global scale.

Ballast water, essential for the structural stability of ships, can transport and release thousands of aquatic organisms, from microorganisms to invasive species, into ecosystems lack natural defenses against them. This unintentional biological transfer has been associated with profound ecological impacts, alterations in ecosystem functionality, and the spread of pathogens (Ruiz *et al.*, 2000; Davidson, Minton, Carney, Miller & Ruiz, 2017).

In response to this emerging risk, the international community has strengthened regulations on ballast water management, particularly through the implementation of Regulation D-2 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, established by the IMO, which aims to ensure that ballast water management complies with microbiological criteria and the respective discharge limits into the sea, as shown in Table 1 (IMO, 2004).

The three target microorganisms are recognized pathogens. *Vibrio cholerae* is part of the aquatic microbiota and has more than 200 known serogroups, only two of which cause cholera; other serogroups do not cause cholera but can cause bloody diarrhea, gastroenteritis and extraintestinal infections (Bakalar, 2016). For its part, *E. coli* is a bacterium that normally inhabits the intestines of humans and warm-blooded animals, and some of its strains can cause gastrointestinal, urinary, or systemic diseases. Its presence in environmental waters is considered an indicator of fecal contamination,

and it is discharged into the environment through faeces or wastewater effluents (Jang *et al.*, 2017).

Enterococci are opportunistic bacteria that can cause a large number of infections in humans and animals. Since they are excreted in faeces, they are commonly found in contaminated water and are easy to culture in the laboratory. These characteristics have favored their use as microbiological indicators of fecal contamination and as substitutes for waterborne pathogens in research studies and water quality monitoring programs around the world, especially in contexts of exposure to recreational waters (Byappanahalli *et al.*, 2012).

Furthermore, in Colombia, DIMAR, through Resolution 477 of 2012, has adopted specific verification and monitoring measures, with technical support from the Oceanographic and Hydrographic Research Center of the Caribbean (CIOH), to control the entry of invasive organisms via Colombian Caribbean ports.

In this context, the present study aimed to evaluate the presence and concentration of pathogenic microorganisms in ballast water discharged by international vessels in Colombian Caribbean ports, in order to establish compliance

with current international and national standards and provide technical evidence to guide decision-making in the environmental management of maritime transport. This research thereby seeks to contribute to the protection of marine ecosystems, while also strengthening the role of Colombian ports as responsible actors in sustainable maritime trade.

Table 1. Discharge limits as set out in the IMO D-2 standard

Microorganism	Discharge limit
<i>Vibrio cholerae</i>	<1 UFC/ 100 ml
<i>Escherichia coli</i>	<250 UFC/ 100 ml
Intestinal enterococci	<100 UFC/ 100 ml

STUDY AREA

During the years 2020-2023, fifteen (15) international vessels arriving at the ports of Coveñas (Sucre), Cartagena (Bolívar), Puerto Bolívar (La Guajira), Santa Marta (Magdalena) and Barranquilla (Atlántico), whose locations are shown in Figure 1, were randomly selected for the purpose of verifying their ballast water management.

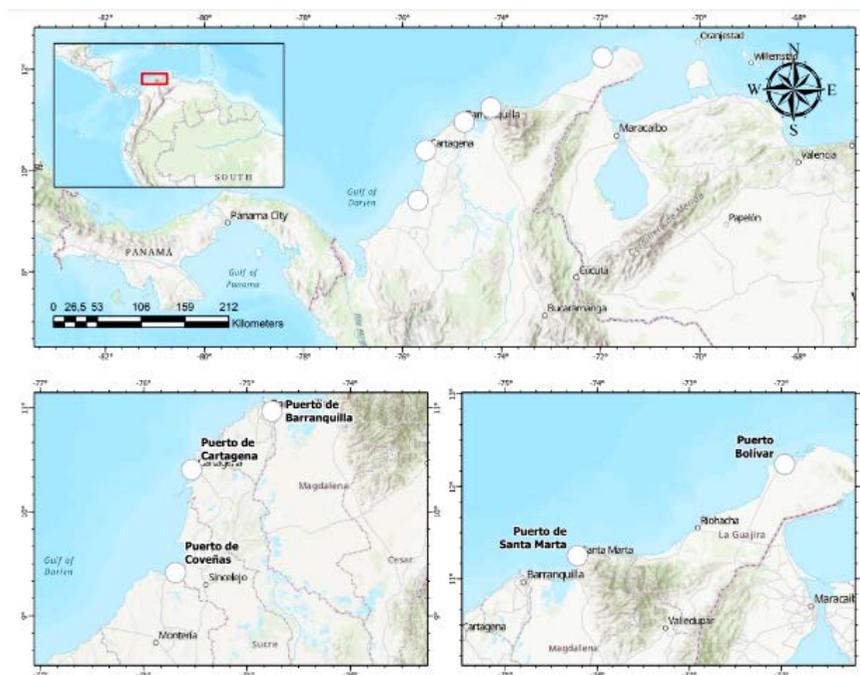


Figure 1. Location of the ports Coveñas-Sucre, Cartagena-Bolívar, Puerto Bolívar-La Guajira, Santa Marta-Magdalena and Barranquilla-Atlántico.

METHODOLOGY

Microbiological sampling

We used 500 ml Schott® glass bottles to collect microbiological samples. Prior to the start of the research, they underwent a special washing and disinfection process to ensure sterile conditions during sampling. They were then packed and labeled with Kraft paper to ensure correct identification.

Sampling was carried out by collecting ballast water from the ships' manholes using a Niskin bottle. This equipment was inserted into the ballast tank until the desired depth was reached,

allowing a representative sample to be taken. Once collected, the water was transferred to the Schott® bottles, leaving an air space inside each bottle to facilitate homogeneous agitation of the sample during the subsequent analysis in the laboratory (Fig. 2).

Finally, the samples were stored in portable coolboxes with ice, ensuring a storage temperature below 10°C while they were transported to the laboratory.



Figure 2. Microbiological sampling of ballast water on board ships

Processing of microbiological samples

The samples were prepared in the field, following the protocols established by the Dimar laboratory at its Caribbean Headquarters, in order to preserve the integrity of the samples and ensure reliable microbiological results.

The analytical techniques used for each parameter are described in Table 2. Microorganism detection methods have varied over the years,

in accordance with the laboratory procedures in force at the time (Dimar). However, all of them are considered valid and meet the technical standards and capabilities that were applicable at the time. Microbiological analyses focused on the detection and quantification of *Vibrio cholerae*, *E. coli*, and intestinal enterococci as indicators of microbial contamination in ballast water.

Table 2. Analytical techniques used to detect *Vibrio cholerae*, *E. coli* and intestinal enterococci

Year of sampling	Parameter	Technique	Reference standard	General description
2020 - 2021	<i>Vibrio cholerae</i>	Membrane filtration	Modified SM 9260H (APHA/AWWA/WEF,2017).	Enrichment: 1 % Alkaline Peptone Water Agar: TCBS, BHI, CromoAgar Incubation temp: 35±2°C Incubation time: 18 to 24 hours Biochemical tests: String and oxidase
	<i>Escherichia coli</i>	Membrane filtration	SM 9222D (APHA et al., 2017).	Selective agar isolation: m-FC Incubation temp: 44.5 ± 0.2°C Incubation time: 24±2 hours Confirmation tests in: EC-MUG broth, Lauryl Tryptose broth, BRILA broth, Indol and Citrate
	Intestinal enterococci	Membrane filtration	SM 9230C (APHA et al., 2017).	Selective agar isolation: m-Enterococcus, BHI Incubation temp: 35±0.5°C Incubation time: 48± 3 hours Confirmation tests in: BHI broth, Bile esculin agar, BHI broth, BHI broth with 6.5 % NaCl
2023	<i>Vibrio cholerae</i>	Membrane filtration	Modified SM 9260H (APHA, et al., 2017).	Enrichment: 1 % Alkaline Peptone Water Agar: TCBS, BHI, CromoAgar Incubation temp: 35±2°C Incubation time: 18 to 24 hours Biochemical tests: String and oxidase
	<i>Escherichia coli</i>	Membrane filtration	Modified ISO 9308-1:2014/A1:2017 (International Organization for Standardization, 2017).	Selective agar isolation: CCA Incubation temp: 36 ± 2°C Incubation time: 21-24 hours Confirmation tests in: Indol
	Intestinal enterococci	Membrane filtration	UNE-EN ISO 7899-2:2000 (Asociación Española de Normalización, 2000).	Selective agar isolation: Slanetz and Bartley agar (m-Enterococcus agar) Incubation temp: 36±2°C Incubation time: 44± 4 hours Confirmation tests in: Bile esculin agar

Documentary evidence support

To support the findings of this research, various documentary sources were collected and analyzed, such as ship records, documentation traceability, and current regulations related to the subject of study. These documents were selected for their relevance and reliability, with their authenticity verified through the review of official sources.

The documentary evidence was mainly used to contrast the information obtained through interviews and observations, allowing for data triangulation and strengthening the validity of the results. All documentation was safeguarded in both digital and physical formats, in accordance with the confidentiality protocols established for the research.

RESULTS

During the period 2020-2023, there was no growth of *Vibrio cholerae* in any of the tanks sampled on the fifteen (15) ships selected. *E. coli* growth was only detected in one of the samples: tank WBT4S of the UBC Savannah, sampled in the port of Barranquilla in 2023, with a result of 3 CFU/100 ml. Nevertheless, this concentration is below the limit permitted by Dimar Resolution 477 of 2012.

In contrast, the presence of intestinal enterococci was more frequent, being detected in seven (7) of the fifteen (15) ships analyzed during the period. In two of these cases, the concentration exceeded the maximum values established in the regulations: the ship Jackeline C., in the port of Cartagena (2020), with 152 CFU/100 ml; and UBC Savannah, in the port of Barranquilla (2023), with 158 CFU/100 ml, as shown in Table 3.

Table 3. Results of the microorganisms found in the ballast water from the ships sampled during the period 2020-2023.

Year	Area	Ship	Tank	<i>Vibrio cholerae</i> (CFU/100ml)	<i>E. coli</i> (CFU/100ml)	Intestinal enterococci (CFU/100ml)
2020	Coveñas	Eagle Kinarut	3BS	<1	<1	2
			6BS	<1	<1	22
			6P	<1	<1	23
	Cartagena	Velos Aquarius	3 PORT WGT	<1	<1	<1
			4 PORT WGT	<1	<1	9
			3 STBD WGT	<1	<1	3
			4 STBD WGT	<1	<1	5
		Velebit	WBT 4P	<1	<1	<1
			WBT 2P	<1	<1	<1
			WBT 2S	<1	<1	<1
		Jackeline C.	3SWBT	<1	<1	152
	5SWBT	<1	<1	97		
	5BWBT	<1	<1	53		
	Silver Manoor	5WBTS	<1	<1	<1	
		5WBTP	<1	<1	7	
	Aurora N	T5	<1	<1	<1	
		T4P	<1	<1	<1	
T3S	<1	<1	<1			

Year	Area	Ship	Tank	<i>Vibrio cholerae</i> (CFU/100ml)	<i>E. coli</i> (CFU/100ml)	Intestinal enterococci (CFU/100ml)
2021	Santa Marta	Elizabeth II	5 TST	<1	<2	<1
			6 TST	<1	<2	<1
			4 TST	<1	<2	<1
		Tiger South	WBT 5	<1	<2	<1
			WBT 4	<1	<2	<1
		BW Japan	1TSWB	<1	<2	<1
	3TSWB		<1	<2	<1	
	Puerto Bolívar	Algoma Victory	ST1P	<1	<2	1
			ST1S	<1	<2	<1
		Green Universe	ST 3T	<1	<2	3
			ST 1T P	<1	<2	8
			ST 1T S	<1	<2	<1
	UBC Santa Marta	4WB P	<1	<2	<1	
4WB S		<1	<2	<1		
2023	Cartagena	CMA CGM BERLIOZ	NO5 SWBT(P)	<1	<1	<1
			NO5 SWBT(S)	<1	<1	<1
		Polar Brasil	4BWTP	<1	<1	<1
			4BWBTS	<1	<1	<1
	Barranquilla	UBC Savannah	WBT4S	<1	3	15
			WBT4P	<1	<1	158

Note. The results highlighted in gray show that microorganisms were present, while those highlighted in red exceeded the permitted values

During the analysis of the results, the documentary evidence collected—such as technical maintenance records, the traceability of ship documentation, and current regulations—served as complementary evidence to contrast the information obtained through interviews and observations.

These documents made it possible to verify the correspondence between the practices reported by the personnel and the procedures officially established, highlighting both consistencies and gaps in the application of ballast water treatment systems. The documentary review also provided regulatory and technical context that strengthened the interpretation of the findings and allowed for a better understanding of the variations observed among different vessels.

These findings reflect compliance with the parameters established by international regulation

D-2 for *Vibrio cholerae* and *E. coli*, but warn of recurrent detection of non-compliant levels of intestinal enterococci. This may indicate specific deficiencies in treatment systems or in on-board maintenance and monitoring protocols. (IMO, 2004).

Discussion

According to the results obtained from monitoring the ballast water tanks of ships that arrived at Colombian ports between 2020 and 2023, it was found that the concentrations of the microbiological indicators *Vibrio cholerae* and *Escherichia coli* complied with the permissible limits established in Regulation D-2 of the International Convention for the Control and Management of Ships’ Ballast Water and Sediments (IMO, 2004). However, the presence of intestinal enterococci was detected on the vessels Jackeline C. and UBC Savannah, which were sampled in the ports

of Cartagena (2020) and Barranquilla (2023), respectively.

This situation could be related to variability in the efficiency of ballast water treatment systems, which can perform poorly or well depending on their design, maintenance and operating conditions (Bakalar, 2016).

According to the documentation submitted by the ships' crews, most of the treatment systems use combined mechanical filtration and ultraviolet (UV) radiation technologies; this is an effective method, albeit with limitations against certain resistant organisms, such as some types of phytoplankton and zooplankton. Bacteria, on the other hand, tend to be more sensitive to UV radiation (Nanayakkara *et al.*, 2011). Various studies have shown that the combination of mechanical separation and UV radiation increases the rate of microorganism inactivation (Hess-Erga *et al.*, 2019; Romero-Martínez *et al.*, 2014).

In contrast, the UBC Savannah uses a filtration system combined with electrochlorination, a technology considered highly effective for ballast water disinfection, particularly in scenarios where there is a high microbiological risk. This system generates chlorine in situ by electrolysis of a saline solution, which enables the inactivation of bacteria, viruses and other pathogens (Hess-Erga *et al.*, 2019). While various studies have demonstrated its effectiveness against the planktonic organisms covered by the D-2 standard, its main disadvantage is its high operating cost (First *et al.*, 2016; Tsolaki & Diamadopoulos, 2010).

The detection of bacterial growth in these ships could be related to operational failures in the treatment systems, such as poor maintenance, inadequate salt or chlorine concentrations, or the presence of biofilms in the pipes, which compromises the effectiveness of the process (Stehouwer *et al.*, 2015).

Intestinal enterococci were the most prevalent of the bacteria studied, as they are microorganisms that tolerate adverse conditions such as pH changes, high salt concentrations and the presence of disinfectants; they also survive better in contaminated water and soil compared to other species of the same genus (Byappanahalli *et al.*, 2012).

The detection of pathogens in the ballast water of international shipping vessels is essential due to its importance in sanitation, as it contributes to the prevention of infectious diseases. A contaminated vessel can become a source of outbreaks on board and there is a risk of these spreading at the port of destination. From an environmental perspective, this control prevents the introduction of invasive species and microorganisms that alter local marine ecosystems and displace native species, thereby reducing the negative impacts on fauna and flora caused by non-native microorganisms (Sellera *et al.*, 2024).

Finally, this study constitutes a first attempt to demonstrate the current state of compliance with Regulation D-2 by ships entering Colombian Caribbean ports (IMO, 2004).

As a projection for future research, this study provides a methodological basis for establishing correlations between process traceability and control systems, considering whether they may be applicable as performance indicators in microbiological testing.

CONCLUSIONS

The results obtained during this research confirmed the initial hypothesis: adequate monitoring of the ballast water used by international shipping is essential to mitigate the introduction of non-native species and protect marine ecosystems. The analysis of microbiological indicators revealed the potential presence of microorganisms that could alter the natural balance of aquatic ecosystems, confirming the need for rigorous monitoring of ballast water. The study also found that the treatment systems used by ships not only comply with current regulatory requirements, but also optimize the operational efficiency of these vessels by reducing the pollutant load before discharge.

This research will enable future lines of work to be carried out, such as the development of more efficient technologies for the treatment of ballast water, comparative studies between different treatment systems, and the assessment of long-term ecological impacts in regions exposed to international maritime traffic. The findings presented here reinforce the importance of comprehensive and proactive management

in international maritime transport, aimed at preserving environmental health and the sustainability of the oceans.

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AUTHOR CONTRIBUTIONS

Conceptualization: N.N.C.L.; K.L.S.; Methodology: N.N.C.L.; Formal analysis: N.N.C.L.; K.L.S.; Writing – original draft: N.N.C.L.; Writing – review & editing: K.L.S.; Supervision: K.L.S.

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RESEARCH ARTICLE

Assessment of coastal erosion and accretion in outer Buenaventura Bay between 1969 and 2023

Evaluación de la erosión y acreción costera en la bahía externa de Buenaventura entre 1969 y 2023

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ABSTRACT

This article presents the results obtained from the analysis of the evolution of the coastline between 1969 and 2023 in the sectors of Soldado Island, Santa Bárbara Island, Bazán Bocana and Pianguita (outer Buenaventura Bay, Colombia). The digitization of the coastline was carried out from a geomorphological and physiographic perspective, and DSAS (Digital Shoreline Analysis System) software was used to quantify the changes. Erosion/accretion rates, net shoreline movements and the greatest distance between all shorelines regardless of dates were calculated, finding that erosion and accretion rates at Bazán Bocana and Pianguita were within the range of ± 2 m/yr, at Soldado Island between 10.7 and -10.74 m/yr, and Santa Bárbara Island between 5.9 and -8.92 m/yr. We therefore classify these shorelines as stable at Bazán Bocana and Pianguita, and with high erosion and accretion on the islands.

KEYWORDS: Shoreline, coastal erosion, accretion, Pacific, Colombia

RESUMEN

Este artículo presenta los resultados obtenidos del análisis de la evolución de la línea de costa entre 1969 y 2023 en los sectores de isla Soldado, isla Santa Bárbara, Bazán Bocana y Pianguita (bahía externa de Buenaventura). La digitalización de la línea de costa se realizó bajo una perspectiva geomorfológica y fisiográfica, y para la cuantificación de los cambios se utilizó el software Digital Shoreline Analysis System (DSAS, por sus siglas en inglés). Se calcularon las tasas de erosión/acreción, los movimientos netos de la línea de costa y la mayor distancia entre todas las líneas de costa independientemente de las fechas, encontrando que las tasas de erosión y acreción fueron en Bazán Bocana y Pianguita estuvieron dentro del rango ± 2 m/año; en isla Soldado, entre 10.7 y -10.74 m/año, e isla Santa Bárbara, entre 5.9 y -8.92 m/año; clasificando estas líneas de costa como estables en Bocana y Pianguita, y con erosión y acreción alta en las islas.

PALABRAS CLAVES: línea de costa, erosión costera, acreción, Pacífico, Colombia.

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INTRODUCTION

Coastal erosion is defined as a retreat of the coastline or the erosion of beaches as a result of the interaction between the materials that make up the coastline, and natural and anthropogenic erosive agents (Ungrd, 2017). The interest that the population has in coastal areas due to its provision of commercial, tourist, transport, resource and communication opportunities (Cohen *et al.* 1997 in Dimar-CCCP, 2013) has exerted strong pressure on these areas, leading to habitat destruction, pollution, erosion and resource depletion, generating conflicts between users and socio-economic problems (MinAmbiente, 2017).

Currently, at a global level, coastal retreat due to erosion is recognized as one of the main threats to coastal areas, and one that is related to sea level rise due to climate change, since rising sea levels increase the threat to coastal areas from natural disasters, with this increase being directly proportional to the magnitude of the disasters, meaning, therefore, that the areas of flooding produced are more extensive (Duncan *et al.*, 2008).

In Colombia, the Caribbean and Pacific coastlines are no strangers to these erosion processes, which are the result of natural forces or human intervention, leading to changes in these coastlines. According to Correa and Vernette (2004), Invemar-GEO (2015), Paniagua (2013) and Vernette *et al.* (2012), these processes have intensified over the last three decades, becoming a problem that leads to the loss of beaches, cliffs and other coastal landforms (Posada *et al.* 2009). With the intention of preserving and/or generating profits in these locations, construction projects have been carried out for coastal protection and recreational purposes without the relevant studies, which in most cases have had the opposite effect to the desired one.

These coastlines have been studied in recent decades by numerous authors, including Cardona (2018), Castañeda (2017), Coca and Ricaurte (2019), Coca and Ricaurte-Villota (2022), Correa *et al.* (2007), Correa and Vernette (2004), Ferrucho-Maloof *et al.* (2022), González and Correa (2001), Paniagua (2013), Posada *et al.* (2009) and Zambrano and Andrade, (2011). The main objective of some of these studies is to examine

erosion processes due to their high impact on ecosystems and human settlements, while their effect on socio-economic and environmental areas has been evaluated, as explained by Coca and Ricaurte (2019), who determined the vulnerability of different populations to coastal erosion.

In the area of interest, several studies have been conducted on the advances and retreats of the coastline, and to characterize depositional and erosional landforms. One such study is that of Posada *et al.* (2009), which describes the type of coastline, the associated rock type (cohesive and non-cohesive) and the factors involved in sedimentation and erosion processes, as well as a general characterization of the area and 1:100,000 scale maps of geomorphological units, geomorphological features, sedimentary facies and the coastline. Alejandra *et al.* (2017) determined the magnitude of the change in the coastline north of the district of Buenaventura using 30m resolution Landsat satellite images from 1986, 2001 and 2015, finding that at La Bocana and Punta Soldado the erosion/accretion rates were between 5 and -5 m/year; Invemar-GEO (2015), in a technical report describing the recent evolution of the coastal zone of the province of Valle del Cauca, analyzed the coastline of the Punta Soldado sector between 1971 and 2015, finding that between 1971 and 2011 the coastline receded 85 m, and between 2011 and 2015 it receded 47 m. However, there are no studies that characterize the evolution of the coastline in all the study sectors of this publication with high spatial and temporal resolution.

At the time of writing, there are no previous studies on the movements of the coastline in the areas analyzed that use a detailed 1:5,000 scale, nor any with a time series as wide as the one used in this research (1969, 1982, 2006, 2016 and 2023). The aim of this article is to quantify the net movements of the coastline, as well as the erosion and accretion rates in the outer part of Buenaventura Bay. For this reason, we used the DSAS software developed by the United States Geological Survey (USGS), using historic photography from Colombia's Agustín Codazzi Geographical Institute (IGAC), orthophotography and satellite imagery taken between 1969 and 2023. The analysis is focused on the sectors of Soldado Island, Santa Bárbara Island, Bazán Bocana and Pianguita.

STUDY AREA

The study area is located in the outer part of Buenaventura Bay. It includes the sectors of Pianguita and Bazán Bocana, as well as Soldado and Santa Bárbara Islands, all part of the municipality of Buenaventura, in the province of Valle del Cauca on the Colombian Pacific coast (Fig. 1). Geomorphologically, Punta Soldado and

Santa Bárbara are barrier islands with vegetated intertidal plains and beaches, landforms associated with the interaction of the sea and the rivers that discharge there, such as the Raposo, Dagua and Anchicayá. To the north, at Bazán Bocana and Pianguita there are beaches, coastal plains and hills.

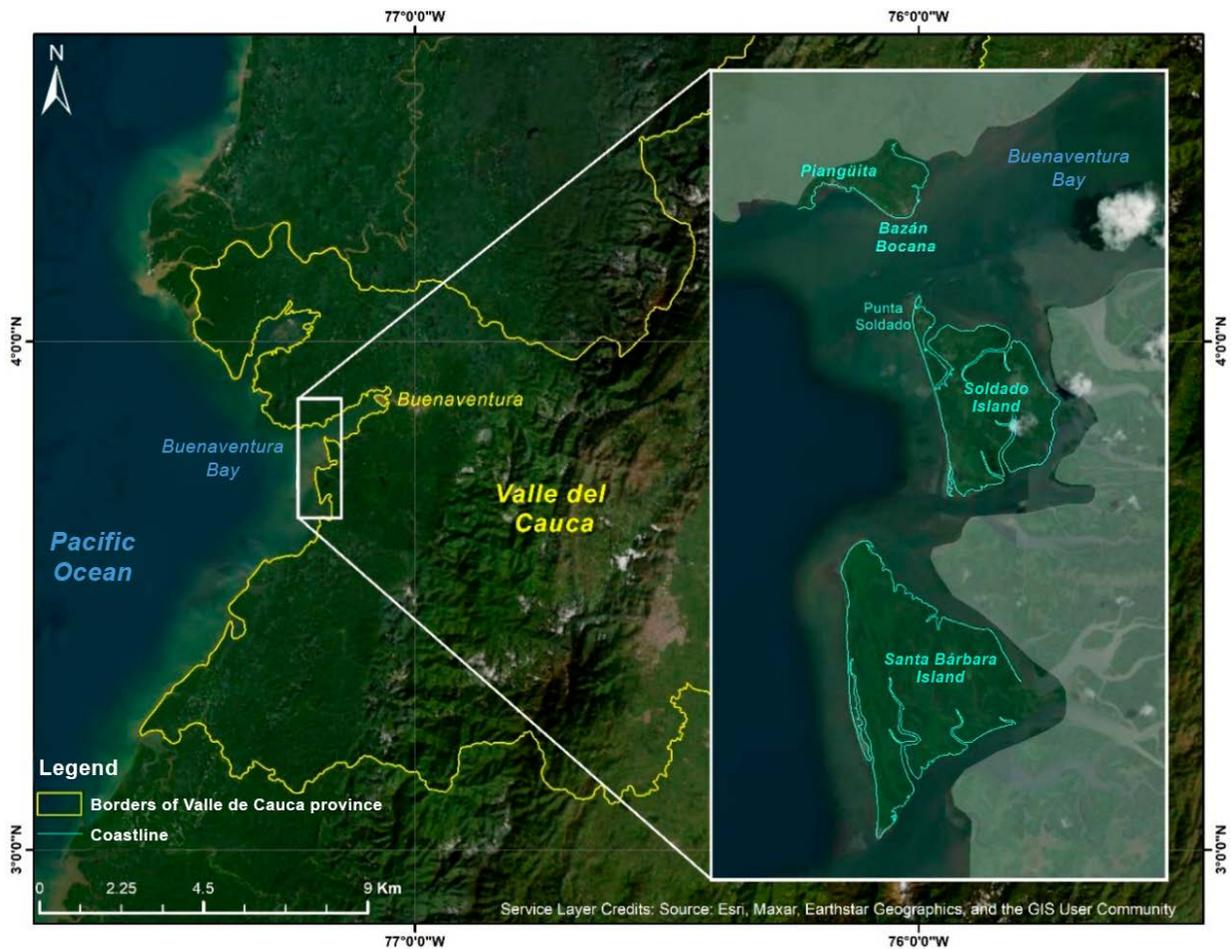


Figure 1. Location of the study area

METHODOLOGY

Data

The coastlines were extracted using aerial photographs from the IGAC, orthophotographs and satellite images from different dates, as shown in Table 1:

Table 1. Remote sensors

Remote sensor	Resolution	Year	Observations
IGAC Photography	0.9 meters/pixel	1969 y 1982	Dimar database
Orthophotographs	0.25 meters/pixel	2006	Dimar database
Satellite images	0.3 meters/pixel	2016	Maxar constellation – Dimar database
Satellite images	5 meters/pixel	2023	Sentinel 2 satellites downloaded from LandViewer

Criteria for defining the coastline and digitization process

The coastline was digitized at a 1:5,000 scale to suit the photo-interpretation that was made with the lowest resolution satellite images (5 m resolution from Sentinel 2), complemented in some sections by higher resolution images without reduction, in order to preserve relevant geomorphological details. The criteria used in this digitization process were defined from the following geomorphological and physiographical perspective (Fig. 2):

- **Rocky coasts:** directly connected with the sea, the coastline is defined using the base of the cliff or the edge of the rocky outcrop (Ojeda Zújar *et al.*, 2013) (Fig. 2a).
- **Mangroves:** these grow in intertidal zones and one of their main ecosystem services is to protect the coast from erosion. In this case, the coastline is defined by the coastal edge of the mangrove (Fig. 2b).
- **Beaches:** defined by the internal boundary between the dry beach (backshore) and the permanent vegetation or coastal dune, if there is one (Fig. 2c).
- **Infrastructure in direct contact with the sea:** defined by the external edge of the infrastructure that is in contact with the sea (Fig. 2d).

The coastlines were digitized by a single person who is an expert in the field in order to minimize the inevitable subjectivity in the photo-interpretation process, and always at the same scale (1:5,000) in order to guarantee geometric coherence (Ojeda Zújar *et al.*, 2013)

Measuring change and calculating erosion rates

To measure the net changes in the coastline and calculate the rates of erosion, we used DSAS, a piece of software that is compatible with ArcGIS. To use this software, the user must create a coastline for each year for which measurements will be made, and a digitized baseline approximately parallel to and at a prudent distance the coastline, which serves as the starting point for the different orthogonal transects that intersect the coastlines. The tool generates semi-automatic transects once the analyst has designated the distance between them (Fernández de la Torre, s.f.). For this study, the distance between transects was set at 50 m, a reasonable separation given the scale of the work. The statistics calculated by the DSAS software during this process were:

- **Net Shoreline Movement (NSM):** calculates the net movement of the coastline, that is the movement between the oldest coastline and the most recent one.
- **End Point Rate (EPR):** calculates the rate of change in the coastline in meters per year, in other words the ratio of NSM divided by the time elapsed.
- **Shoreline Change Envelope (SCE):** calculates the greatest distance between all the coastlines registered, independently of the dates (Himmelstoss *et al.*, 2021).

To classify the level of coastal erosion and accretion, we adapted the categories of coastal evolution proposed by Del Río *et al.* (2013), which are presented in Table 2:



Figure 2. Criteria for digitizing the coast lines. a. Coastline defined by the cliff base; b. Coastline defined by the coastal edge of the mangrove in intertidal zones; c. Coastline defined by the landward boundary of a beach; d. Coastline defined by the edge of infrastructure.

Table 2. Classification of the level of accretion and erosion [Taken from: Del Río *et al.* (2013)]

Range of EPR (m/year)	Classification of the coastline change processes
< -15	Very high erosion
-5 to -15	High erosion
-2 to -5	Moderate erosion
-2 to 2	Stable
2 to 5	Moderate accretion
5 to 15	High accretion
>15	Very high accretion

RESULTS

Bazán Bocana and Piangüita

The results obtained from the DSAS software show that the coastlines at Bazán Bocana and Piangüita have remained stable, since the EPR is within the range of -2 to 2 m/year. There have been negative NSM movements (erosion) of up to -86.2 m, and positive movements (accretion) of up to 87.1 m. The SCE calculation shows that the greatest movement in the coastline was 87.1 m (Fig. 3). In general, of the 4.07 km of coastline

analyzed in this study, 35.44 % have eroded and 64.56 % have accreted; however, these processes have been slow, since the EPR values have been within the range for a stable coastline (-2 to 2 m/year) (Table 2).

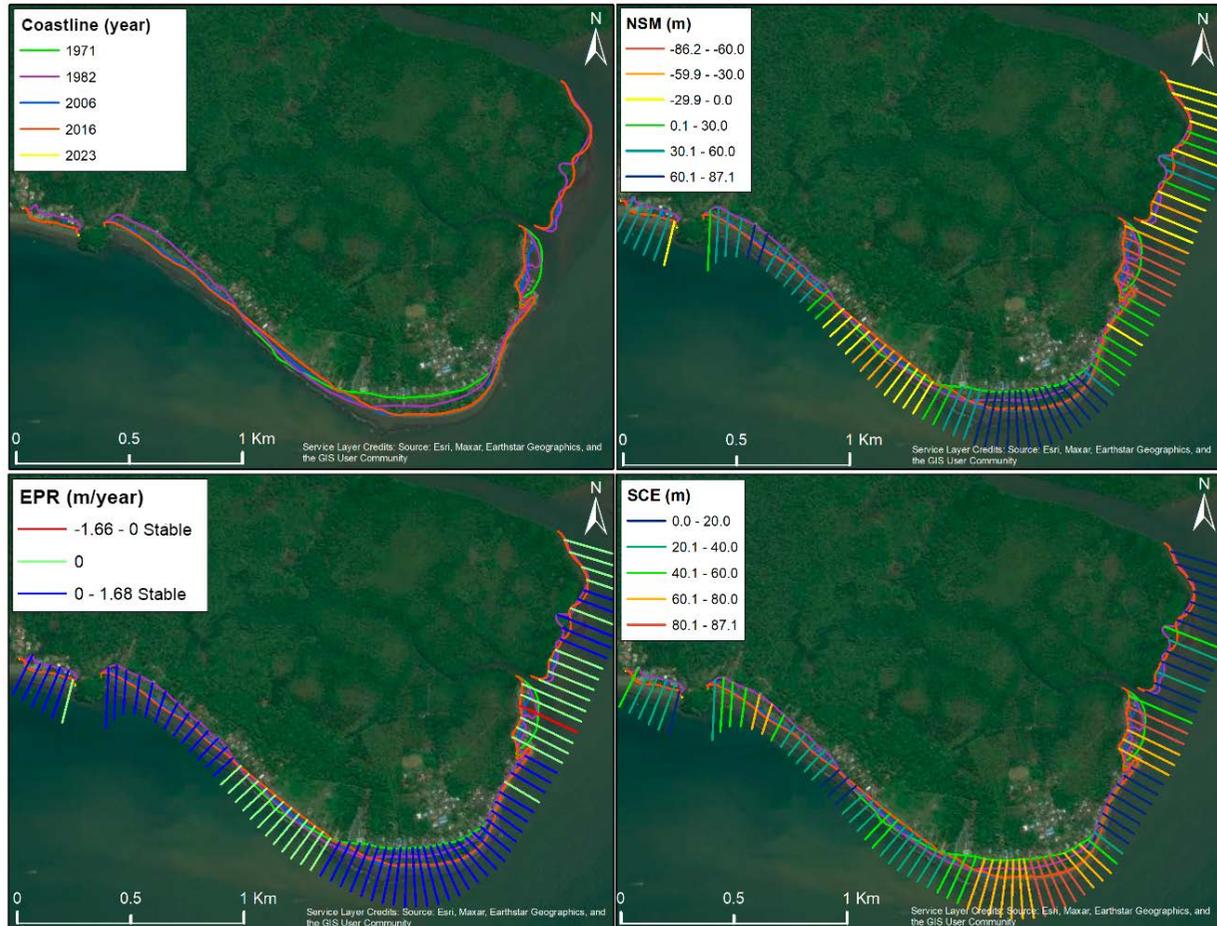


Figure 3. Evolution of the coastline in the Bazán Bocana and Pianguita sector, and results of the NSM, EPR and SCE statistics.

Soldado Island

The results obtained for Soldado Island show that the coastline has experienced high erosion, with EPR values that reach -10.7 m/year, and high accretion of up to 10.7 m/year. The NSM values show that the coastline has had negative net movements (erosion) of up to -558.5 m and

positive ones (accretion) of up to 556.4 m. The SCE figures show that the greatest difference between coastlines in this sector was 620 m (Fig. 4). In general, of the 10.36 km of coastline analyzed in this sector, 77.6 % have eroded and 22.4 % have accreted (Table 3).

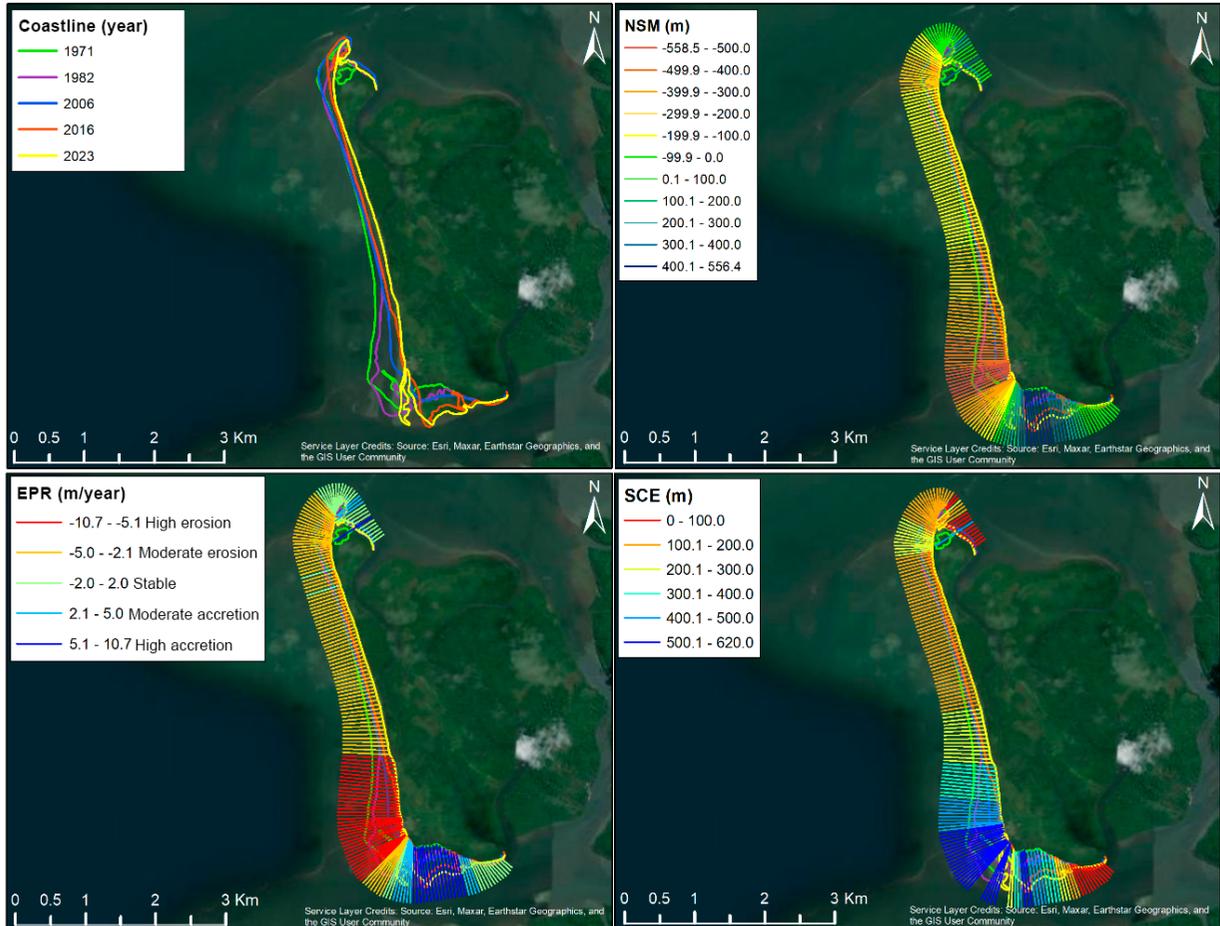


Figure 4. Evolution of the coastline in the Soldado Island sector, and the results of the NSM, EPR and SCE statistics

Santa Bárbara Island

The results obtained for Santa Bárbara Island demonstrate that the coast line has experienced both high erosion, with EPR figures that reached as much as -8.9 m/year, and high accretion, with values of up to 5.9 m/year. The NSM values show that there have been net negative coastline movements (erosion) of up to -233.9 m/year and

net positive movements (accretion) as high as 306.8 m. The SCE figure shows that the greatest difference between coastlines in different years was 373.1 m (Fig. 5). In general, 35.5% of the 12.6 km of coastline in this sector has eroded and 64.5% has accreted (Table 3).

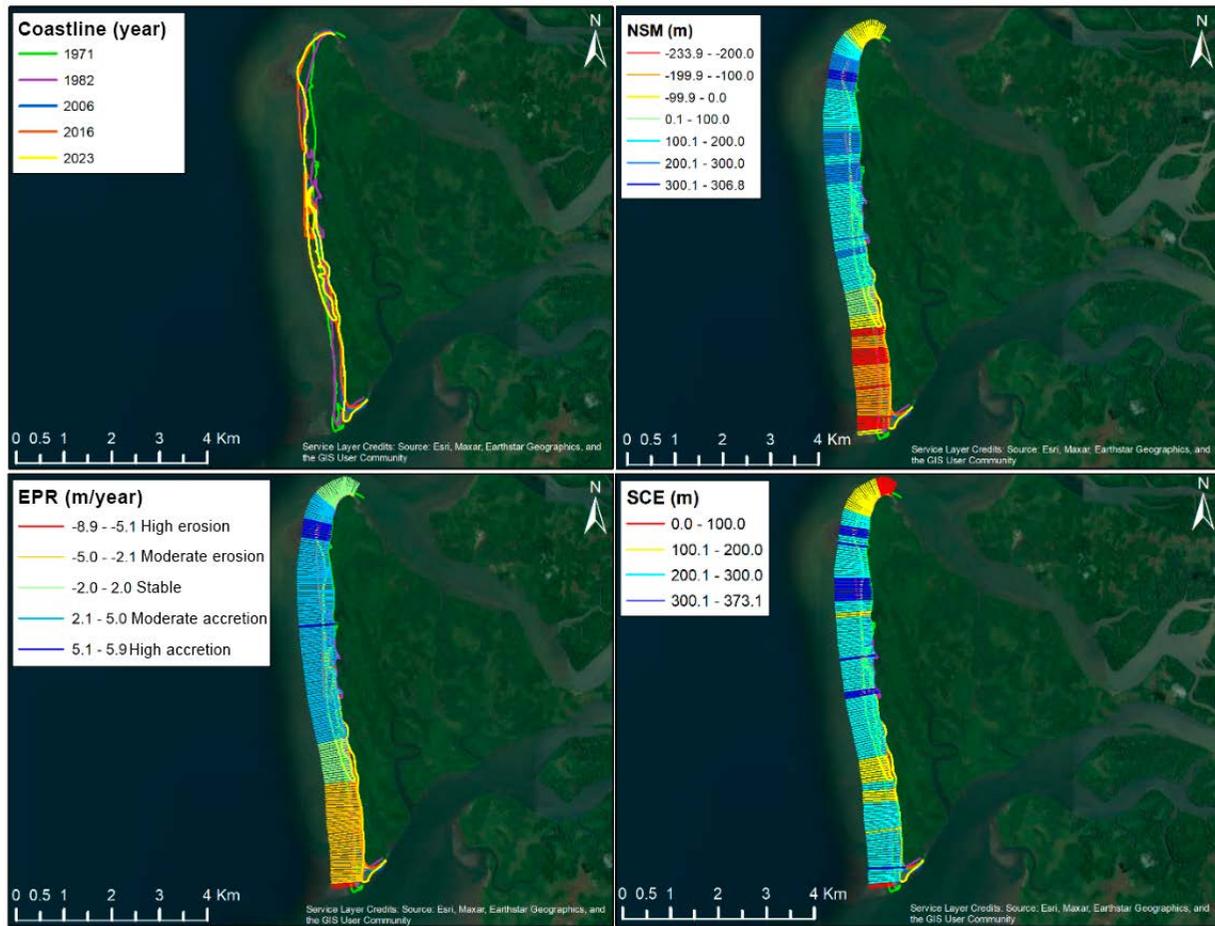


Figure 5. Evolution of the coastline of Santa Bárbara Island, and the results of the NSM, EPR and SCE statistics

Table 3. Results of the EPR, NSM and SCE statistics around the study area

Statistic	Bazán Bocana and Piangüita	Soldado Island	Santa Bárbara Island
% of the coastline that has eroded	35.44	77.6	35.45
% of the coastline that has accreted	64.56	22.4	64.55
Maximum accretion NSM (m)	87.11	556.37	306.76
Average accretion NSM (m)	43.67	216.4	168.08
Maximum erosion NSM (m)	-86.18	-558.51	-233.93
Average erosion NSM (m)	-30.45	-210.6	-138.06
Maximum accretion EPR (m/year)	1.68	10.7	5.9
Average accretion EPR (m/year)	0.84	4.16	3.23
Maximum erosion EPR (m/year)	-1.66	-10.74	-8.92
Average erosion EPR (m/year)	-0.59	-4.05	-2.83
Maximum SCE (m)	87.11	620.47	373.14
Mean SCE (m)	41.21	263.22	226.96

DISCUSSION

The evolution of the coastline in Buenaventura Bay in recent years has been conditioned by its geomorphology, which, in turn, depends on the lithological characteristics of the zone and its interaction with the exogenic and endogenic processes that shape it, for example, marine meteorology and tectonics. The geomorphology of the northern section of the outer bay is characterized by hills and slopes in the main, with some smaller beaches (Bazán Bocana and Piangüita). Hills and slopes formed by a poorly lithified sedimentary sequence of sandstones, conglomerates and shales of continental and marine origin (SGC and UNAL, 2015) surround some of the beaches in the area, providing them with some protection from the hydrodynamics of the area, as evidenced by the beaches of Bazán Bocana and Piangüita, which have been classified as stable, since the rates of change in the coastline when the sea has advanced or retreated have not exceeded ± 2 m/year.

On the other hand, in the southern part of the bay, Soldado Island and Santa Bárbara Island are characterized by being low plains directly exposed to fluvial-marine dynamics and anthropogenic activities. These characteristics explain the more pronounced changes in the coastline here than in other parts of the bay.

On Soldado Island, the highest erosion rates (-10.74 m/year) were observed in the south, around the settlement that gives the island its name, and the highest accretion rates (10.70 m/year) were observed at the southern tip of the island. It can therefore be inferred that the sediment lost in the sector where the coastline receded the most was redeposited at the southernmost tip of the island, possibly influenced by wave dynamics. Erosion and accretion rates are moderate (± 2 to 5 m/year) towards the north-central and northern parts of the island; however, the same pattern of sediment rearrangement can be seen: a decrease in the width of Soldado Island (due to coastline retreat) and an increase in its length due to sediment rearrangement towards the northern and southern tips. This study quantified changes in the coastline by averaging them over a period of 52 years; however, the results in the Invemar-GEO (2015) and Eisinguer (2023) studies show that between 2011 and 2021 the erosion rates

on the island have reached levels of between -19.25 and -22.10 m/year. In the last decade, the most significant coastline retreats were observed between 2014 and 2016. According to the National Oceanic and Atmospheric Administration (NOAA), the El Niño event in 2015-2016, classified as "very strong", may have been associated with the coastline retreat in those years.

In the case of Santa Bárbara Island, there has been mainly moderate erosion in the south, with coastline retreats of between -2 and -5 m/year, plus a few areas of high erosion, with values reaching -8.9 m/year. Towards the centre and north of the island, moderate accretion has predominated, with coastline advances of between 2 and 5 m/year, although there are some zones where it has remained stable (± 2 m/year) or experienced high accretion (between 5 and 5.9 m/year). Compared to Soldado Island, this island has undergone fewer changes in its coastline, and its length has remained relatively stable.

CONCLUSIONS

The northern part of outer Buenaventura Bay, Bazán Bocana and Piangüita, is where the coastline has receded or advanced the least in the last 54 years, while on Soldado Island these changes have been very significant in terms of land loss and gain.

At Bazán Bocana and Piangüita, during the study period, 35.44% of the coastline receded (erosion) and 64.56% advanced (accretion). However, according to the results, erosion and accretion rates range from 1.68 to -1.66 m/year, so the coastline in this sector was classified as stable. As the maximum erosion/accretion rates are so similar, as are their averages (0.84 and -0.59 m/year), it can be concluded that sediment has been rearranging itself along the coastline in this sector.

On Soldado Island, 77.6% of the coastline receded due to erosion processes and 22.4% advanced as a result of accretion processes. Erosion/accretion rates range from 10.70 to -10.74 m/year, so the coastline was classified as having high erosion and accretion. Like in the north of the study area, the maximum erosion/accretion rates were very similar to each other, as were the averages (4.16 and -4.05 m/year), so it

can be inferred that the sediment was rearranged along its coastline.

On Santa Bárbara Island, 35.45% of the coastline receded and 64.55% advanced. The range of erosion/accretion rates was 5.9 to -8.92 m/year, which is why the coastline was classified as having high erosion and accretion. The maximum erosion rate is higher than the maximum accretion rate, but the averages of these rates were very similar, 3.23 and -2.87 m/year, and the percentage of coastline that advanced was much higher than that which receded; therefore, it can be concluded that there was a slight gain in sediment accumulation on the beaches of this island.

AUTHORS' CONTRIBUTIONS

Abstract: K. A. E. V.; Introduction: K. A. E. V.; Study area: K. A. E. V.; Methodology: K. A. E. V. - D. C. N. P.; Results: D. C. N. P.; Discussion: D. C. N. P.; Conclusions: D. C. N. P.

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