Scientific and technological research article

Co-participatory identification of the impacts of climate change on the maritime cultural heritage of Tierra Bomba Island, Cartagena de Indias, Colombia

Identificación coparticipativa de los impactos derivados del cambio climático sobre los patrimonios culturales marítimos en la isla de Tierra Bomba, Cartagena de Indias, Colombia

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Abstract

Climate change currently represents one of the greatest risks for the development of biodiversity and the social and cultural sustainability of human beings throughout the planet. This paper presents the partial results of the pilot phase of research which developed a space designed for community actors interested in generating a proposal for identifying the effects of climate change on the maritime cultural heritage of the island of Tierra Bomba, in Cartagena de Indias (Colombia). This project, called "Colaborartorio Azul", is a co-participatory laboratory interested in articulating the different community, institutional and academic knowledge on Climate Change and its impact on the natural-cultural heritage of the maritime and coastal landscape of the city and some of its population centers.

Keywords: Climate change, cultural heritage, knowledge co-production, Tierra Bomba, Cartagena de Indias, Colombia.

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Resumen

El cambio climático representa en la actualidad uno de los mayores riesgos para el desarrollo de la biodiversidad y la sostenibilidad social y cultural de los seres humanos en todo el planeta. En este trabajo se presentan algunos de los resultados de la fase piloto de una investigación en la cual se desarrolló un espacio diseñado para actores comunitarios interesados en generar una propuesta para la identificación de los efectos que produce el cambio climático en los patrimonios culturales marítimos de la isla de Tierra Bomba, en Cartagena de Indias (Colombia). Dicho proyecto, denominado "Colaborartorio Azul", es un laboratorio coparticipativo interesado en articular los diferentes saberes comunitarios, institucionales y académicos sobre el cambio climático y su impacto en el patrimonio natural-cultural del paisaje marítimo y costero de la ciudad, y algunos de sus centros poblados.

Palabras claves: *cambio climático, patrimonio cultural, coproducción del conocimiento, Tierra Bomba, Cartagena de Indias, Colombia.*

Introduction

Climate change is generating impacts in all areas of contemporary society. As it is a threat to human well-being, social sciences play a key role in understanding and mitigating these impacts (Rivera-Collazo, 2021). In relation to cultural heritage, at the international level, some reports have been published in recent years. In 2005, the World Heritage Committee focused attention on climate change, understood as a threat to global heritage assets, by adjusting the application form for inscription on the World Heritage List, which must now list the changes and impacts caused by climate change, such as floods, earthquakes, and other natural disasters (Unesco, 2005). Subsequently, in 2014, the United Nations Educational, Scientific and Cultural Organization (Unesco) supported the development of a practical guide on climate change adaptation at four heritage sites in Kenya and India, providing theoretical and practical examples for planning a climate adaptation strategy.

However, this remains a recent and underexplored topic (Morel *et al*., 2022). Most of the work has highlighted the risks and threats (Barba, Díaz, & Luna, 2010; Ezcurra & Rivera, 2018; ICOMOS, 2020; Unesco, 2005, 2022; Reeder-Myers, 2015), but also the possibilities and potential of maritime and underwater cultural heritage in the face of climate change (Guiao, 2020; Unesco, 2021). It is worth noting that with the Paris Agreement (UN, 2015), the importance of intangible cultural heritage in adaptation actions to climate change is recognized.

In this sense, decisions should:

> *"[...] be based on and inspired by the best available scientific information and, where appropriate, traditional knowledge, indigenous peoples' knowledge, and local knowledge systems, with a view to integrating adaptation into relevant socio-economic and environmental policies and measures, as appropriate"* (UN, 2015, p. 10).

Therefore, community participation and cultural heritage play a fundamental role in the formulation and implementation of climate change adaptation actions, as they could increase effectiveness, efficiency, sustainability, and inclusivity (Guiao, 2020).

On the other hand, climate change can have negative impacts on maritime and underwater cultural heritage, causing both direct and indirect damage to material assets and intangible practices, whether viewed from a physical or social context (Unesco, 2015). Particularly, in a survey conducted by the World Heritage Center in 2005, the impacts of climate change on sites designated as world heritage were assessed. Based on responses received from 83 participating countries, the most recurrent climate-related threats identified were hurricanes and storms, rising sea levels, wind or water erosion, floods, increased precipitation, drought, desertification, and rising temperatures (Unesco, 2007). Thus, it becomes a priority to implement short-term research and management models that integrate communities and their traditional knowledge with

the scientific sector, given the urgency of the impacts and losses to cultural heritage (Figueira & Howard, 2019). In addition to displacing a culture from the land where its physical heritage is located, climate change can irreversibly transform its traditions and knowledge (Henriksen, 2007).

For the specific case of Cartagena de Indias, due to environmental issues such as coastal erosion, rising sea levels, and flooding affecting the cultural heritage on Tierra Bomba Island (Del Cairo *et al*., 2022; Riera & Báez, 2022), and more broadly in the city of Cartagena (Distrito de Cartagena de Indias, 2016; Villarreal, 2019), it is necessary to establish protection mechanisms that incorporate multiple community, institutional, and academic perspectives. According to research by authors such as Andrade (2008); Andrade, Ferrero, and León (2017); Rangel and Montealegre (2003); Pabón (2003a; 2003b); Pabón and Lozano (2005); Torres and Tsimplis (2013), it has been shown that the upward trend in relative sea level in Cartagena is two to three times greater than in Cristóbal (Panama), Magueyes (Puerto Rico), and Lime Tree (Florida Keys). While for these cities, the relative sea level rise trend ranges between 1.3 mm and 1.9 mm per year, in Cartagena, it varies between 4.5 mm and 5.3 mm per year. This represents a risk to the conservation of cultural heritage located on the city's coastline, as the accelerated rise in sea levels can lead to structural damage and eventual disappearance over time.

Thus, the inter-institutional approach must be accompanied by an interdisciplinary perspective that can establish a support network for this collaborative space where shared participation is a cross-cutting axis for generating knowledge about climate change and its impact on cultural heritage, and designing solutions and alternatives for its mitigation. Building on the above, the project 'Colaborartorio Azul: Effects of Climate Change on Cultural Heritage Sites in Cartagena de Indias, Colombia' (Del Cairo *et al*., 2023) was born as a study that, from an archaeological, anthropological, and historical perspective, aims to identify, investigate, and analyze the impacts of climate change on cultural heritage. This is done through a participatory approach alongside the communities of Cartagena de Indias, providing valuable data for current and future risk reduction measures and contributing to the identification of different response strategies for protecting cultural heritage from the impacts of climate change.

This co-participatory approach aims to establish networks of exchange between public and private stakeholders, academia, and the community for the continuous development of protection mechanisms and concerted decision-making that make community participation in public heritage protection both viable and sustainable (Forero, Hernández, & Zafra, 2023). A lack of awareness or coordination of impacts from the community's perspective increases the likelihood of producing maladaptive plans and actions that can result in irreversible changes or greater losses (Moshenska, 2014). In this regard, this article presents partial results from the "Colaborartorio Azul" project in its pilot phase (Del Cairo *et al*., 2023), which analyzes the impacts of climate change based on historical documentation and cartography, as well as the integration of local knowledge through community participation regarding climate change and its impact on the cultural heritage of Tierra Bomba Island.

Study Area

Tierra Bomba Island is located south of the urban area of Cartagena de Indias and north of the Barú Peninsula. The island is divided into four townships: the eponymous Tierra Bomba, Punta Arenas, Caño de Loro, and Bocachica, all of which have a rich cultural potential resulting from historical and territorial processes related to the sea (Villa, Cáceres, & Arrieta, 2019). In terms of maritime cultural heritage (Fig. 1), this area encompasses various tangible expressions of the daily life of the local residents, which interact with immovable heritage (fortifications, wells, cisterns, among others).

They contain a diversity and richness of intangible and material maritime-coastal cultural heritage within themselves (Rubio-Ardanáz, 2014; Rozo-Pinzón, 2020; Del Cairo *et al*., 2022; 2023). Particularly, we worked with the communities of Bocachica on the forts of San José, San Fernando, and San Luis; with the inhabitants of Tierra Bomba at the San Bernabé tile- and brickworks, and with the residents of Caño de Loro on the structures near the old leprosy hospital.

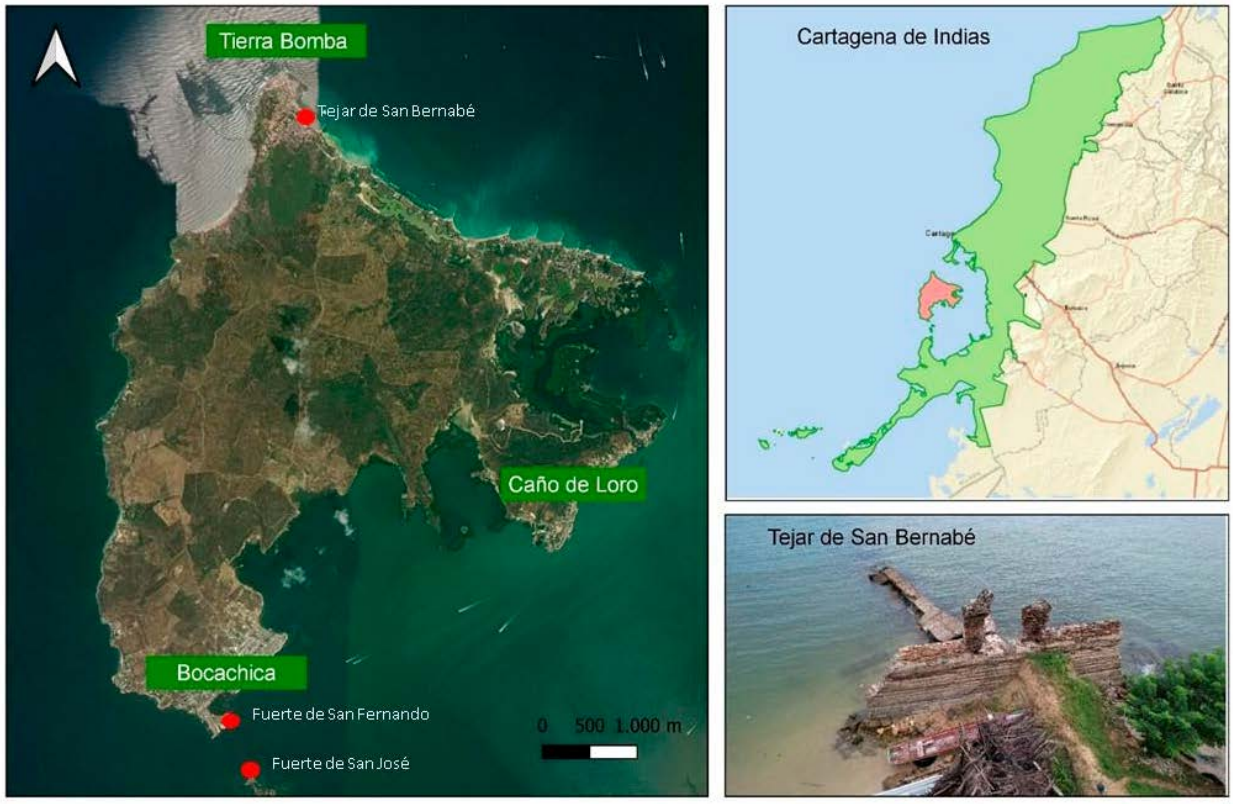

Figure 1. Location of the study area and aspects of cultural heritage (San Bernabé tile and brickworks). The map shows the analyzed sectors: Tierra Bomba, Bocachica, and Caño de Loro.

Despite the rich cultural and heritage assets of the island, the community of Tierra Bomba finds itself in a state of neglect by certain national institutions due to their limited presence in the area. This is reflected in the living conditions of the residents and their access to essential services (Picó *et al*., 2013). For example, 96.7% of the 12 207 inhabitants in 2019 lives in extreme poverty conditions: they lack sewerage, drinking water, and landline telephone services. Natural gas was installed only in 2016, and electricity in 2003. Additionally, there are problems with inadequate housing and overcrowding (Del Cairo *et al*., 2023).

Regarding environmental vulnerability, despite the island's abundant natural resources, factors such as rising sea levels, flooding, improper solid waste management, coastal erosion, and the use of fuels like wood make it susceptible to climate change (Cáceres & Romero, 2017; González & Torres, 2019), affecting both its residents and the material cultural heritage of the area (Parra & Anaya, 2017). There are also serious issues related to pollution, drug addiction, gangs, and violence, leading to an environment of insecurity and division within the community. This has resulted in fragmented and individualistic communities (Caraballo, 2020).

Current trends such as the privatization of coastal areas on the island for the construction of exclusive hotels and tourist sites have exacerbated these social issues on the island. While these activities contribute to tourism development, they have led to the neglect of local communities and created barriers within the territory, limiting the mobility of locals and, consequently, access to archaeological and natural sites (Iregui &

García, 2016; Rozo-Pinzón, 2020). Bocachica, the township with the most archaeological and historical sites on the island, provides a clear example of territorial division due to the pressure emanating from the exclusive hotel industry, which has been privatizing the coastal area of the district. These exclusive services have gradually taken over the coastal zone and displaced locals (Rozo-Pinzón, 2020).

Methodology

A preliminary mapping of actors and stakeholders was carried out to build a support network that strengthened the capacities of the "Colaborartorio Azul" project from various social, academic, economic, and technological perspectives. A methodological proposal with a co-participatory approach was implemented to identify the impacts of climate change on maritime cultural heritage on Tierra Bomba Island. This approach horizontally integrated local communities into the activities carried out to achieve the project's objectives. In this sense, the island's residents became the key players in identifying the impacts of climate change on cultural heritage. This was achieved by valuing and recognizing the traditional knowledge and practices of communities in relation to changes in weather patterns, which were then integrated where there were gaps in the scientific information.

Thus, through the development of working groups, workshops, surveys, and visits to cultural resources (Fort San Fernando, the San Bernabé tile- and brickworks, Fort San José, and the leprosy hospital) during the last quarter of 2022, communities engaged in the co-creation of knowledge and the development and strengthening of research capacities to enable governance and the protection of the territory and its heritage at different temporal scales of analysis. The information encompassed quantitative and qualitative data:

- First, the "long-term" scale was addressed through primary and historical sources such as historical maps, travelers' notes, and navigation diaries. These sources allowed the definition of natural features, along with perceptions and events that helped characterize the climate and heritage, and their transformations over time.
- Secondly, the "medium-term" scale was addressed through practical exercises with the community. Tools such as field diaries, audiovisual records, social mapping, the Mandala methodology[9], and other participatory dynamics were used to reconstruct a landscape memory that led to the identification of alterations caused by climate change in relation to the physical environment and the traditional practices of the current community.
- Finally, the "short-term" scale involved a practical component including monitoring, recording climate conditions, and establishing recording points, among others. The purpose of this exercise was to design measurement mechanisms and tools for assessing the effects of climate change on the cultural heritage of the area.

Analysis of the impacts of climate change according to historical documentation

This research reviewed cartographic sources (Table 1) and satellite images, which formed the basis for a historical characterization of transformations in the local maritime and coastal cultural landscape. This allowed us to register the environmental processes that have occurred in Cartagena de Indias, particularly on Tierra Bomba Island. The analysis of historical cartography involved three phases: *(i)* Collection and selection of historical cartography: After obtaining an initial database with information for each of the analyzed sites, specific historical cartographic references were chosen for the overlay. *(ii)* Overlay of historical maps with aerial photography using ArcMap (utilizing ArcGIS software): To perform georeferencing, reference points that had remained constant over time, such as the fortifications in Cartagena Bay, were used, preferably in locations from different parts of the map to maintain the image's proportional relationship. *(iii)* Tracing and vectorization of different coastlines on the maps: Some maps displayed coastlines from different years, and these coastlines were traced and vectorized.

[9] Framework that allows for the systematic gathering of both general and specific information aimed at identifying the socio-cultural universe of the community through various activities and objects associated with daily life.

Table 1. Primary Cartographic Sources Consulted.

Title	Year	Author	Source
Map of the City of Cartagena de Yndias, located at 10 degrees and 26 minutes of northern latitude and 304 degrees of longitude.	1716	Anonymous	AGI MP-PANAMA,123
Map of the Bay of Cartagena de las Yndias, surveyed by Field Marshal Don Juan de Herrera y Sotomayor, Military Engineer of this Town, and outlined by Captain of Horses Don Carlos de Briones Hoyo y Abarca, Lieutenant Military Engineer and Castellan of the Castle of San Felipe de Barajas.	1721	Juan de Herrera y Sotomayor	Biblioteca Digital Hispánica No. bdh0000031660
Island of Tierra Bomba: Map of the Peninsula of Tierra Bomba and Carex, which explains the division of a land cavalry of the College of the Society of Jesus with the lands of Captain Don Alberto de Sucre according to the Commitment.	1734	Anonymous	AGI MP-PANAMA,261
Grundriss Cartagena in Indien, 1735.	1735	Ulloa, Antonio de Arévalo	Bibliothèque nationale de France, GED-2372 (VII)
Map of Cartagena de Indias [General map of the square of Cartagena de Yndias, part of its bay, and the surrounding land to understand the location of the Bocagrande opening, a dangerous threat to this square and the Isthmus square that lies between them...].	1769	Antonio de Arévalo	Biblioteca Virtual de Patrimonio Bibliográfico MN — Signatura: 28-A-14
Map of the Bocachica channel, the only entrance for ships to the bay of Cartagena de Yndias and the adjacent land on its northern and southern sides, created in accordance with the order of His Majesty on October 18, 1768. This map is intended to show the impact the sea has had on this area from October 1757 until the present day, as well as the necessity of providing the boats called "betas", as provided for in the aforementioned Royal Order to extract the sand deposited by tides and winds.	1792	Antonio de Arévalo	Cartografía y relaciones históricas de ultramar; Servicio Histórico Militar, Servicio Geográfico del Ejército Tomo V
Map of the port of Cartagena de Indias, the city situated at a latitude of 10° 26 '07'' N and a longitude of 69° 20' 01'' W of Cadiz. [Nautical chart] by the Spanish Directorate of Hydrographic Works.	1809	Anonymous	Institud Caartografic i Geologic de Catalunya
Cartagena	1885	Anonymous	CO.AGN.SMP.4,REF.X-71
Map of the Port of Cartagena de Indias, the city located at a latitude of 10° 26' 07'' N and a longitude of 75° 33' 10'' W of Greenwich.	1910	Vergara y Velasco, Francisco Javier 1860-1914	Biblioteca Nacional de Colombia fmapoteca_1332_fbnc_110
Aids to navigation in service in Cartagena Bay	1973	Anonymous	Acero Rangel, J. A. (2019). Sistema de ayudas a la navegación de Colombia: del acetileno al monitoreo remoto "Una luz para arribar seguro a puerto"

Articulation of knowledge about climate change

In order to generate horizontal knowledge about the impacts of climate change on Tierra Bomba Island and, in general, on Cartagena de Indias, workshops were held to build the general foundations about the impacts of climate change on maritime cultural heritage, bringing together the main social actors from the townships and institutional entities (Fig. 2). These workshops were attended by representatives of the Tierra Bomba Island community, members of the foundations Vigías de Karex and Los Jagüeyes, the General Maritime Directorate (Dimar), the Institute of Cultural Heritage of Cartagena, the University of Cartagena, the Cartagena de Indias School Workshop (ETCar), and the Naval Museum of the Caribbean.

In the first workshop (Fig. 3), held at the University of Cartagena in November 2022, an introductory activity focused on discussions about six key aspects: climate change, its impact on the community, the maritime coastal environment, heritage, climatic variables, and the units of observation for these impacts. To do this, readings from 20th-century newspapers were used to explore topics related to floods, rainfall, cyclones, storms, and other effects on coastal areas and heritage sites (Fig. 3).

Figure 2. Participants and activities of the first working group.

Figure 3. Workshop discussion around 20th-century newspaper articles.

Participants were also consulted on their perspectives, reflections, and perceptions regarding the effects of climate change and their connection to maritime and coastal cultural heritage. Once the information provided by the community was compiled and digitized, it was analyzed in the context of scientific research conducted in the area.

Diffusion and dissemination strategy

As part of the measures to capture and disseminate the research results, a strategy was implemented to catch the interest of the target audience and create a virtual community that offers training and builds community capacities in theoretical and practical skills that would allow for the diagnosis of the impacts of climate change on regional heritage (Del Cairo *et al*., 2023).

Results and Discussion

As a result of the preliminary mapping activities of the target audience and actors, a support network was built to strengthen the capabilities of the "Colaborartorio Azul" project from various social, academic, economic, and technological fronts. Among the entities identified with the greatest potential were: the Naval Museum of the Caribbean, Dimar, the Port Captaincy of Cartagena, the Center for Oceanographic and Hydrographic Research of the Caribbean (CIOH), the Cartagena School Workshop, Cartagena City Hall, the Cartagena Institute of Cultural Heritage, the Conservar Group, and the Community Museum of Tierra Bomba. Organizations like Vigías de Karex, Cartagena Divers and the University of Cartagena, and international actors, especially the University of California and the University of Panama, were also highlighted (Del Cairo *et al*., 2023).

Impacts of climate change according to historical documentation

By overlaying historical information, it was possible to identify how the island of Tierra Bomba has undergone significant transformations over the centuries (Fig. 4), attributed to both human and natural actions. For instance, in the case of human actions, in the northern sector of the island, during the 17th and part of the 18th century, it was connected to the Bocagrande peninsula by a land bridge. However, starting in the second half of the 18th century, with the opening of the channel and, consequently, the construction of the submerged breakwater, the morphology of the northern part of the island changed.

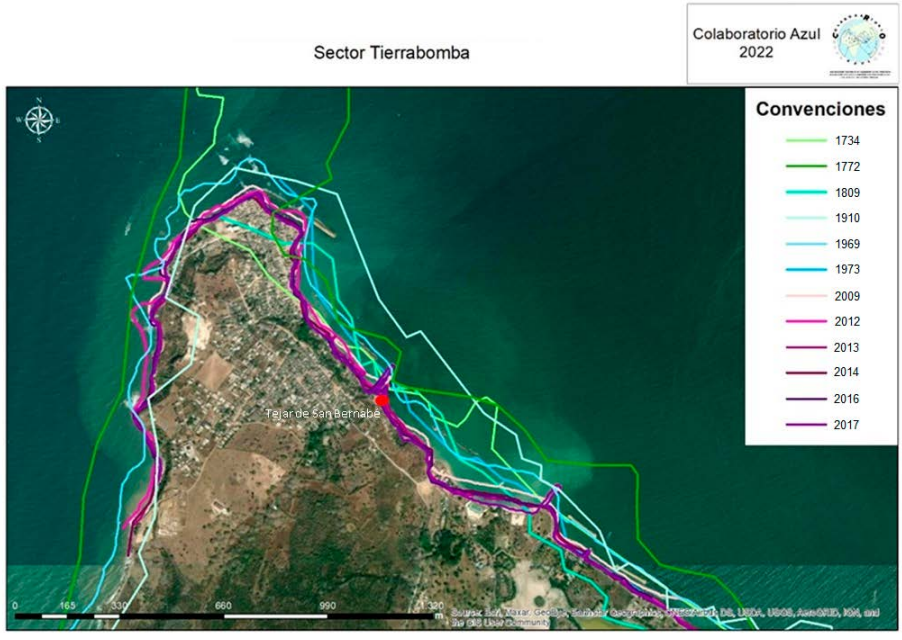

Figure 4. Evolution of the coastline in the Tierra Bomba sector from the 18th century to the 21st century.

This fact serves as an important precedent to consider for the analysis of the coastline. However, starting in the 20th and 21st centuries, coastal erosion of up to 265 m is identified in the northern part of the island. When examining temperature changes in Cartagena de Indias over a 42-year period from 1979 to 2021, a gradual increase was observed, with the highest temperatures recorded during the years 2015 and 2016, exceeding 28°C. Therefore, through the cartographic superposition exercise conducted in the framework of the project (Fig. 4) and data collected by other researchers (Andrade *et al*., 2017; Mora *et al*., 2018), it becomes evident that in the last 100 years, more coastline has been lost compared to previous centuries, raising the possibility that this behavior is associated with the effects of climate change.

In the Bocachica sector (Fig. 5), during the late 17th century and the 18th century, several transformations of the coastline are observed, with an increase in sediment deposition, especially in the southern area between San Fernando Fort and Castilletes. The sediment deposition reached up to 94 m between 1698 and 1721 and up to 127 meters between 1721 and 1792 in front of Castillo de San Luis de Bocachica. During the period from 1809 to 1910, a marked trend of coastal erosion is observed, although it is important to note that additional data verification with topographic and bathymetric studies, for instance, is required to obtain more precise measurements of elevation and depth.

Finally, in the Caño del Loro area (Fig. 6), there is a complex morphology that has remained relatively similar over the centuries. This complexity made the cartographic superimposition from the 17th century more challenging. Overall, the Caño del Loro area has shown a tendency toward erosion, as evidenced by wear and retreat of the coastline over the 18th and 19th centuries. Some areas, such as the hospital complex and the Lazaret, have experienced significant erosion in the past 120 years. During the 20th century, there is variability in coastal dynamics in this region.

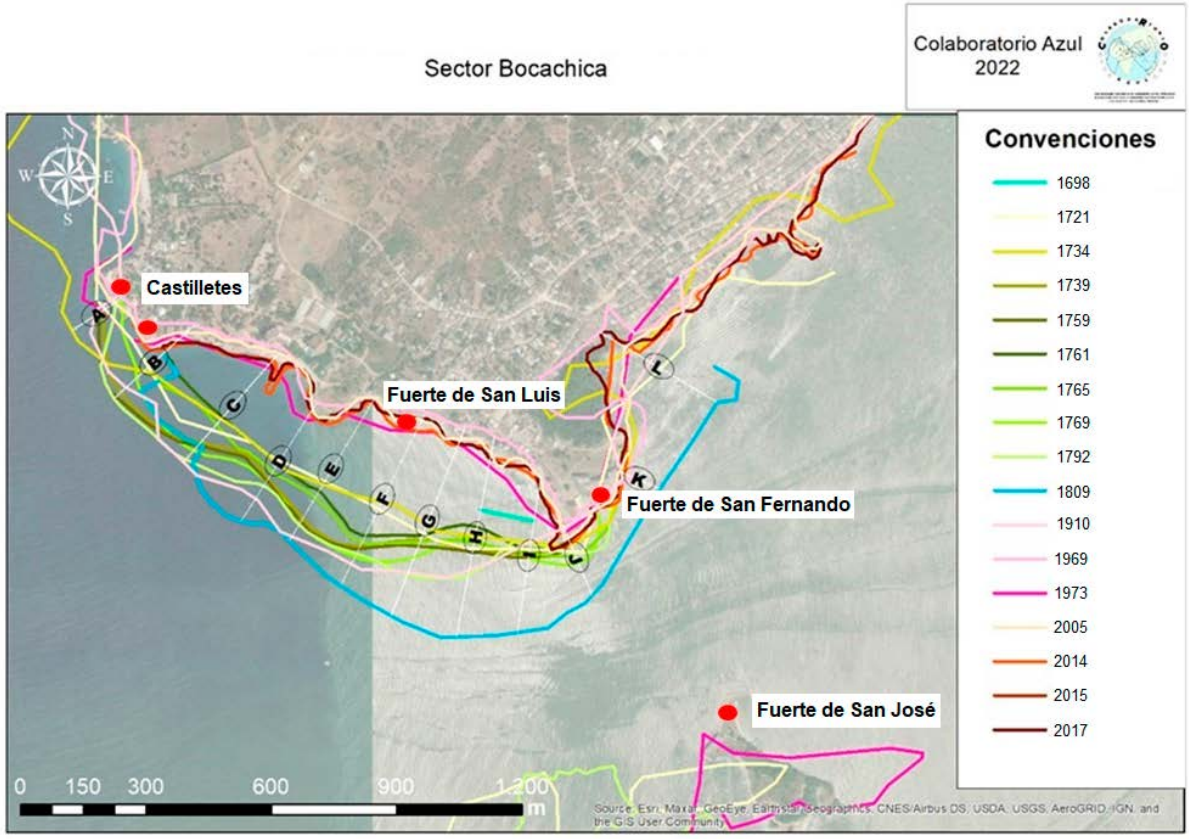

Figure 5. Evolution of the coastline in the Bocachica sector from the 17th century to the 21st century.

Figure 6. Evolution of the coastline in the Caño de Loro sector from the 18th century to the 20th century.

According to Posada, Henao, and Morales (2011), the township of Caño del Loro is subject to flooding caused by storm surges and strong waves generated by merchant ships passing through the area. These activities also lead to erosion, which has necessitated the relocation of some homes. The first line of houses on the northern side of the settlement is heavily affected due to the low-lying terrain, as it is situated on intertidal marshes with anthropogenic fill. Along the coastline, blocks have been positioned and walls built to protect against storm surges.

For the recent period, studies on changes in the coastline of Tierra Bomba Island are scarce, and existing studies are related to human activities. Afanador *et al*. (2008) mentioned that a significant part of its beaches is affected by coastal erosion, and only in some areas has the construction of a series of irregularly distributed groins slightly reduced the retreat of the coastline. Recently, Ricaurte *et al*. (2018) showed that Tierra Bomba is at a high level of threat from coastal erosion on the side facing the bay and very high on the side facing the sea. This is attributed to the lack of natural protective structures guarding it against the waves, which constantly and directly impact the coast, gradually degrading the existing rocky material. However, although the part facing the bay is sheltered from the incident waves (produced by the wind), it may still be affected by waves produced by the passage of boats, which could be one of the significant factors leading to erosion (Amell *et al*. 2012).

Based on the above, it is necessary to consider various hypotheses to confirm whether coastal erosion and sea-level rise are solely indicators associated with climate change. Factors beyond climate change, such as anthropogenic modifications to the environment made during colonial times to ensure the strategic defense of the bay, may have led to variations. For example, dredging in the 18th century in the area of the old military channel of Bocachica, or the construction of the submerged breakwater in the Bocagrande channel. Additionally,

integrating factors associated with geological dynamics, to combine them with the factors described, will help understand the causes of the transformations of the coastline of Cartagena de Indias.

Articulation of knowledge about climate change

As a result of the discussion groups, some environmental variables associated with climatic events were identified (Table 2), not only for Tierrabomba but for other areas of Cartagena. The most representative variables mentioned include rainfall, strong winds, and flooding.

Table 2. Climate variables identified during the workshop that was part of the methodology of this study.

Variables	N° mentions
Rain	17
Wind	16
Flooding	13
Hurricanes	10
High tides	11
Diseases	6
Storms	3
Drought	2
Coastline change	2

Additionally, the community pointed out that the areas most affected by the mentioned phenomena were those located closest to the coastline and in intertidal spaces. Among other territories affected by these same issues, beyond Tierra Bomba, there were other areas that could serve as inputs for new studies, such as El Laguito, Bocagrande, Castillo Grande, the Historic Center, Getsemaní, San Diego, Marbella, and rural areas surrounding the Ciénaga de la Virgen, as well as the rural sectors of Tierra Bomba, Bocachica, and Barú (Fig. 7).

The perceptions of the community (Table 2) can be grouped into atmospheric and marine categories. The atmospheric category includes rainfall, winds, hurricanes, storms, and droughts, while the marine category encompasses high tides and changes in the coastline. Flooding could fall into either category, depending on whether its origin is due to excessive precipitation or variations in sea level.

Furthermore, during visits to three cultural heritage sites, the San Bernabé tile- and brickworks, San Fernando Fort, and the leprosy hospital, which are at higher risk of flooding and the loss of structures caused by erosion and pollution from waste, we identified various factors associated with climatic variables and administrative actions that have contributed to their continuous deterioration.

At the San Bernabé tile- and brickworks, located in the Tierra Bomba district, the decomposition and disappearance of some structural elements were observed. For example, there was evidence of concretions, alterations caused by marine fauna, and erosion. Additionally, it was possible to observe alterations in the sites due to small roots, various insects such as earthworms, spiders, and even dogs. Finally, terrain erosion has resulted in losses of archaeological contexts and the deterioration of artifacts.

Regarding San José Fort, located in the Bocachica district, there were observations of alterations due to the waves impacting the fort's walls. Furthermore, moisture-related deterioration has affected graffiti, and sea level changes have led to the fort being flooded, converting it into a habitat for fauna and flora.

As for the leprosy hospital, located in the Caño del Loro district, vegetation growth, areas inundated by rainfall, and rising sea levels have led to increased damage to the infrastructure.

Considering these contexts, damages to properties, ecosystems, and social systems, including cultural heritage sites, have been mainly attributed to changes in air and water temperature in the atmosphere, which are the primary drivers of the destruction of stone and brick structures (Vyshkvarkova & Sukhonos, 2023). Sesana *et al*. (2021) reviewed the literature investigating the impacts of gradual changes in temperature, precipitation, humidity, and wind on the mechanisms causing the degradation of exposed heritage. According to Sabbioni, Cassar, and Brimblecombe (2009), water is the most important deterioration factor for buildings and especially for historic environments, as it poses a higher risk of moisture penetration into historical materials, including masonry, which, in turn, leads to corrosion and biological colonization.

Figure 7. Areas affected by climatic phenomena identified by the local community. These areas include other places not considered for this case study, although they are useful for final considerations and for planning the continuity of this research.

Regarding sea level variations, the most recent report by the Intergovernmental Panel on Climate Change (IPCC, 2021) shows that, on a global scale, the mean sea level increased by 0.20 m between 1901 and 2018. Locally, the outlook is not encouraging, as coastal subsidence in Cartagena de Indias is occurring at a higher rate than the global sea level rise driven by climate change (Restrepo-Ángel *et al*., 2021).

These authors show that, in a simulated scenario for the year 2100, the eastern side of Tierra Bomba (facing the bay) would be more affected than its western side (facing the sea), with the northeast zone being the most affected. This area falls within the areas defined as flood-prone by Castillo and Gamarra (2014), who refer to marshes and swamps that change in size (opening and closing) depending on the climatic season. The results of these authors also reveal that communities will have different perceptions depending on which side of the island they inhabit.

The meetings and dialogues during "Colaborartorio Azul" with communities, academia, and institutions allowed for understanding, from various perspectives, which climatic factors are currently present and how their transformation and increase over time contribute to the effects and damage present in the environment (landscape) and in the dynamics and quality of life of the communities that inhabit these territories. The most mentioned and recurrent factors were tides, water currents, and winds, followed by heavy precipitation, rising sea levels, and high temperatures. The community also expressed the need to be aware that the behavior of each factor affects the others. Thus, if one is out of balance, it causes the same effect in the others, which is reflected in the daily life of the people on the island, as expressed in one of the excerpts from the interview with the community:

> *"The sea used to be different from how it is now, the sea was calmer. There used to be a breeze like in January, but now it has increased, but now, with the high tides, it brings a different dynamic, I believe the sea is much fuller."* (Excerpt from an interview with Eligio Guerrero, 73 years old, from the Tierra Bomba township; Del Cairo *et al*., 2023).

Diffusion and dissemination

A communication plan was developed, focusing on two main stages. The first stage involved creating a WhatsApp group where the community and institutions could share real-time information about the impacts of climate change in their areas of residence. They were also able to share other relevant posts and all of this helped strengthen inter institutional support networks.

In the second stage, the focus shifted to using digital platforms such as StoryMaps and social media networks like Instagram, Facebook, and LinkedIn. This aimed to create an informative and dynamic online space accessible to interested stakeholders.

The establishment of this virtual network led to discussions and proposals for co-creating strategies to eventually protect maritime cultural heritage. The goal was to help these connected communities understand the effects of climate change and generate mechanisms for mitigating and safeguarding their tangible and intangible cultural legacies (Del Cairo *et al*., 2023).

Conclusions

In Colombia, as the only country in South America to have coasts on two oceans, and one with highly variable geographical characteristics, there is a growing recognition of the need to raise awareness and take action aligned with international policies and guidelines aimed at developing a mitigation strategy for the effects of climate change. The need to structure intersectoral adaptation measures in response to adverse scenarios that may pose risks to both the population and the territories has become increasingly evident. For example, some of the institutions participating in inter-institutional working groups, such as Dimar and its research center CIOH, have developed mechanisms for monitoring and protecting maritime scenarios and marine-coastal ecosystems through scientific research (Vallejo & Pico, 2022; Del Cairo *et al*., 2023).

As a solution to this global issue, various national development plans in Colombia have

incorporated actions, causes, and prevention measures for natural disasters. CONPES document 3990 "Sustainable Bioceanic Potential", published by the National Planning Department, sets the framework for maritime development and discusses the technical weaknesses in managing risks resulting from coastal natural phenomena, including the effects of climate change. For coastal settlements, this implies increased participation in confronting the challenges posed by climate change, as one of its primary impacts is the significant rise in sea levels.

As reflected in multiple primary and secondary sources of information, climate change represents one of the greatest risks to biodiversity, social sustainability, and human culture on Earth. This phenomenon creates a new reality in which environmental factors, such as rising sea levels and atmospheric pollution driven by greenhouse gasses, underscore the urgent need for action. In most cases, industrialized countries are disproportionately responsible for the changes, and developing countries are the hardest hit (Vallejo and Pico, 2022).

Based on the information provided throughout this article and the research conducted, it is evident that the effects of climate change have led to tangible and measurable impacts on the coastal environments of Tierra Bomba. Transformations in natural and cultural resources, as well as impacts on archaeological heritage, traditions, knowledge, and community quality of life, have persisted over time and space due to a lack of education, job opportunities, and access to information. Therefore, the dialogues in horizontal discussion spaces have highlighted the need to find solutions to these challenges given the consequences that affect the communities' living environment. Furthermore, it is crucial to enable the co-production of knowledge within the framework of sustainable local risk management, while preserving the community's past.

With this initial phase of climate change impact assessment, analytical tools have been developed to facilitate comprehensive information conceptualization and provide better management and analysis capabilities. This also serves as a mechanism for environmental monitoring. An indirect impact is the expectation of increased awareness regarding the relationship between climate change and the past, as a natural phenomenon with diachronic anthropogenic influence, through participatory approaches. This aims to empower local communities to deal with its effects, protect their heritage, and address the evident and constant threats they have historically faced and continue to face in the short, medium, and long term.

In conclusion, Colombia is highly vulnerable to the effects of climate change. Given its privileged geographic position, oceanic conditions, and natural resources, it is imperative to develop strategies and policies aligned with international guidelines to strengthen mitigation and adaptation measures for this phenomenon (Cancillería, 2022). As highlighted, climate change is a critical issue that should be the focus of all entities at all levels. Adaptation is key in the search for appropriate strategies to address the impending climate crisis in the coming years, as it will undoubtedly change how nations prepare to face adverse events in a resilient manner.

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Authors' contributions

Conceptualization: C. DelC., G. C., L. R., L. B.; methodology: C. DelC., G. C., J. A., L. B.; analysis: C. DelC., G. C., L. R., S. V., J. A., J. C., L. B.; software: L. R., L. B.; research: C. DelC., G. C., G. H., L. R., J. A., L. B.; validation: C. DelC., G. H., S. V., J. C.; writing and original draft preparation: C. DelC., G. C., L. R., L. B., S. V., J. A., L. B.; proofreading and editing: C. DelC., G. C., G. H., L. R., J. A., J. C., L. B.; supervision, C. DelC., G. C.; project administration: C. DelC.; funding acquisition: C. DelC. All authors have read and agreed to the published version of the manuscript.

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