Ocean Management:

Some Lessons Learned from Tropical Experiences






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1. OCEANOGRAFÍA 2. PESCA ARTESANAL 3. PARQUE NACIONAL ISLA DEL COCO (COSTA RICA) 4. CONSERVACIÓN DE LA BIODIVERSIDAD MARINA 5. SOSTENIBILIDAD 6. RECURSOS MARINOS 7. DERECHO DEL MAR I. Morera Beita, Carlos Manuel, 1966- II. Salgado Silva, Viviana III. Bogan Miller, Mark Whitney IV. Orlich Montejo, Jessie M. V. Avendaño Leadem, Daniel

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Presentation

This book is a coordinated effort from the Vice-Rectorate for Research at the Universidad Nacional (UNA), as part of a series of strategies aimed at fostering interdisciplinary academic work on topics related to ocean management and addressing the challenges faced by coastal communities. This initiative arises from the need to highlight and share Costa Rica's learnings, challenges, and achievements in the sustainable management of its oceanic resources. It compiles relevant cases and experiences that address key aspects such as participatory governance, monitoring, marine ecosystem health and the optimization of marine productivity. Through an interdisciplinary and evidence-based approach, this book aims to serve as a reference for decision-makers, researchers, educators, and coastal communities, both nationally and internationally.

These pages seek to promote a comprehensive understanding of the challenges and opportunities Costa Rica faces in managing its marine ecosystems. From the implementation of legal frameworks and governance instruments to community conservation initiatives and innovative monitoring technologies, the present cases illustrate how good practices can strengthen sustainable development. Furthermore, the book seeks to inspire collective action and foster knowledge exchange to address global threats affecting the oceans.

The first section addresses topics related to maritime law, governance, and the protection of human rights of coastal communities, which are essential to ensure sustainable and equitable use of marine resources. This legal framework not only regulates activities in the maritime domain but also protects the communities that depend on these ecosystems, ensuring them fair access to resources and participation in decision making processes that affect their environment and well-being. Additionally, integrated governance promotes conflict resolution and encourages collaboration between public, private and local sectors, creating a balance between economic development, social justice, and environmental conservation.

The second section explores how scientific monitoring of the oceans is essential for understanding and preserving their crucial role in the planet's balance. From a biological perspective, it is possible to study marine biodiversity, identify changes in species populations, and assess the impact of human activities such as fishing and pollution. Physical oceanography provides information on currents, temperatures, and sea levels, which are essential for predicting extreme weather phenomena and their effects on coastlines. Meanwhile, seismology helps to detect and analyze tectonic movements beneath the seabed, which is key to understanding risks such as tsunamis and submarine earthquakes. Working together, these disciplines offer an integrated vision of the oceans, indispensable for their conservation and for mitigating risks to human communities.

Finally, the third section invites us to reflect on the importance of contributing towards ocean health and productivity to ensure sustainability of the natural resources on which millions of people around the world depend. The oceans are not only home to unique biodiversity, but also regulate global climate, absorb carbon dioxide, and generate more than 50% of the oxygen we breathe. Their productivity supports economies through activities such as fishing, tourism, and maritime transport. Protecting ocean health means combating pollution, mitigating climate change effects, and promoting sustainable practices that ensure resilient ecosystems. A healthy ocean is essential for human well-being and the planet's environmental stability.

Costa Rica, known for its leadership in environmental policies, faces significant challenges in managing its maritime resources. This book not only documents successful experiences but also highlights the importance of integrating multiple sectors in the search for sustainable solutions. In a global context of climate crisis and environmental degradation, Costa Rica's experience can serve as a replicable and adaptable model for other nations. The cases and experiences presented demonstrate how innovation, participation, and scientific knowledge can converge to tackle today's challenges and ensure a resilient future for the oceans.

Dr. Jorge Herrera Murillo
Vice-Rector for Research
Universidad Nacional
December, 2024

Part I
Governance and law

Law of the sea: an urgent legislation for its consolidation

Carlos Murillo Zamora[1]

The legal framework governing the use of the sea has evolved over millennia and reflects humanity's longstanding ambition to influence and control marine spaces. Many of the current regulations concerning the use of maritime spaces date to the Roman Empire and were further strengthened during the 16th and 17th Centuries, particularly through the contributions of European jurists; notably, Hugo Grotius introduced the concept of *mare liberum* (free sea) in opposition to the English doctrine of *mare clausum* (closed sea). However, it was not until the 20th Century when these principles were consolidated into a *Corpus Iuris* through a series of international conferences, including three major

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conferences convened by the United Nations (UN). The most significant was the Third United Nations Conference on The Law of the Sea (1973-1982), which, following extensive preparatory work by UN commissions and resolutions, established a framework for regulating activities in different maritime spaces[2].

The *Corpus Iuris* continued to evolve through various conventions and agreements that established the extent of state jurisdiction over the oceans. However, most of the maritime spaces remained classified as high seas status, characterized by freedom of navigation, overflight, fishing, submarine cable and pipeline positioning, and research (Art. 87, United Nations Convention on the Law of the Sea - UNCLOS). This article embodies the principles of the law of the sea: freedom, sovereignty, and the common heritage of humanity.

Numerous comprehensive works have examined the evolution of the law of the sea and its institutions, (see Tanaka, 2012; Rothwell *et al.,* 2015)[3]. For Costa Rica, see Murillo (2017 and 2005). This historical development has made the law of the sea not only the oldest branch of international law but also one of the most advanced, due to its complexity and relevance for States (Tanaka, 2012, p. 3).

States, particularly coastal nations, that sign and ratify the United Nations Convention on the Law of the Sea (UNCLOS) and its complementary treaties and agreements must adopt domestic legislation to fulfill the purpose of this *Corpus Iuris*. The1984 introduction to UNCLOS describes it as "...multifaceted and constitutes a monument to international cooperation in treaty-making", effectively serving as a constitution for the oceans. Therefore, as stated by UN Secretary General Pérez de Cuéllar, it represents "a transformation of international law" (United Nations, 1984, p. xv).

Without domestic implementation and inter-state coordination, UNCLOS would have remained just another convention. Instead, it has become a dynamic legal instrument requiring states to take a proactive role in upholding the Law of the Sea. This is particularly relevant in 2024,

2 These actions are detailed in the Final Act of the Third United Nations Conference on the Law of the Sea, https://www.un.org/depts/los/convention_agreements/texts/final_act_eng.pdf

3 For a detailed bibliography on the evolution of the law of the sea and the characteristics of each UNCLOS provision, see United Nations (2019).

marking the 30th anniversary of the Convention's entry into force (November 16, 1994). Over these three decades, UNCLOS has functioned as an institutional framework encompassing the Division for Ocean Affairs and the Law of the Sea, under the UN Office of Legal Affairs, and other bodies such as the International Tribunal for the Law of the Sea[4], the Commission on the Limits of the Continental Shelf, and the International Seabed Authority, complemented by the Meeting of party States.

The objective of the article is to assess UNCLOS provisions requiring states to adopt legislation, with a particular focus on Costa Rica, and to evaluate how some measures have been implemented. For this purpose, the status of the Convention is examined in terms of the signing party States. This is complemented by two aspects: (i) the participation of States in UNCLOS-created institutions; and (ii) their involvement in dispute resolution mechanisms. To conclude, reference is made to the status of the High Seas Treaty, with emphasis on Costa Rica's experience.

Party States and the status of UNCLOS

UNCLOS was signed by 119 Member States on December 10, 1982, in Montego Bay, Jamaica. In the end, the final act of the Conference was signed by 23 additional States as full participants. Other actors, such as national liberation movements and intergovernmental organizations, also joined. Part XI -the Zone- required an agreement for its implementation, which entered into force on July 28, 1996. Moreover, on December 11, 2001, the Agreement on the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of December 10, 1982, relating to the conservation and management of straddling fish stocks and highly migratory fish stocks, entered into force.

As of July 2024, 170 countries have ratified the Convention (UNCLOS). Costa Rica was the 51st State to pledge its instrument of ratification on September 21, 1992; the last was San Marino. With respect to the

4 In addition to the Tribunal, according to Article 287, the parties may resolve their disputes through the International Court of Justice, an arbitral tribunal (Annex VII), or a special arbitral tribunal (Annex VIII).

Agreement on Part XI, 153 States approved it (Costa Rica did so in September 2001). The conservation of fishery species has been ratified by 108 countries (Costa Rica formalized its ratification in June 2001. On September 20, 2023, the date on which it was available for signature, Costa Rica[5] signed the Agreement on the Conservation and Sustainable Marine Biodiversity of Areas Beyond National Jurisdiction, also known as the High Seas Treaty, was opened for signature, with Costa Rica signing it on the same date. States may make declarations—intended to specify certain criteria—at the time of signing or ratification, as Costa Rica did.

The number of ratifications for the 1995 Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks is only 93. The purpose of this agreement is to "... ensure the long-term conservation and sustainable use of straddling fish stocks and highly migratory fish stocks through the effective implementation of the relevant provisions of the Convention" (Art. 2 of the Agreement). This convention includes 320 articles grouped into 17 Parts and nine Annexes. Parts One thru Ten can be considered as recording, systematizing, and ordering what could be called the traditional law of the sea, which had been adopted in the Geneva Conventions and other legal texts. From Part XI onward (covering 187 articles), the Convention becomes the most innovative aspect of international law, as it not only establishes rules governing marine spaces but also links them to other global issues. Therefore, it is imperative for states to implement legislation to fulfill the obligations, commitments, duties, and rights generated by UNCLOS.

The Convention and, in general, the related agreements in the various fields require that party States adopt a series of domestic legal and regulatory provisions. This is increasingly becoming more evident as the negative effects of the Anthropocene deepen. This is the only way obligations set out in the Convention can be effective. Thus, the set of international and national rules and practices can contribute to a global maritime order and ocean governance. As Olivert (2022) notes, the role of UNCLOS

5 The annotation that Costa Rica made on December 10, 1982, was "The Government of Costa Rica declares that the provisions of the Costa Rican law on payment of fishing licenses by foreign vessels in the exclusive economic zone, should also apply to the fishing of highly migratory species in accordance with the provisions of articles 62 and 64, paragraph 2, of the Convention".

is realized through the collective confrontation of the challenges and threats facing the oceans. This is a defining feature of the *Corpus Iuris,* as the development of a global ocean order[6] is inseparable from development of international law (Olivert, 2022, p. 26) and the management of maritime and marine spaces by coastal States, as well as by geographically disadvantaged or landlocked states. The international community is facing an unprecedented ocean crisis, characterized by plastic pollution, overfishing, and the effects of climate change, which call for urgent action to ensure the health of the oceans and the planet. However, the magnitude and complexity of these problems demand a coordinated response at the international level, involving all relevant actors, from States to local communities and non-governmental organizations, where Costa Rica has played a role.

Obligations under the UNCLOS framework: implemented through national legislation

UNCLOS established a set of direct obligations arising from the exercise of rights (entitlements) through State actions and complementary international instruments that require implementation by States to ensure compliance with the provisions of the Convention (United Nations, 2004). This is because the Convention's text considers:

> …as the general legal framework within which all activities in the oceans and seas must be conducted. It also establishes the rights and obligations of States when carrying out those activities, including those relating to navigation, living and non-living resources, protection and preservation of the marine environment, marine scientific research, and development and transfer of marine technology, in all maritime areas provided for in the Convention (United Nations, 2024, p. 1).

6 It is actually redundant to allude to a "global order" of the oceans, because when reference is made to the oceans, as opposed to continents and islands, the global dimension is always implied.

Consequently, the law of the sea established in UNCLOS is a "system of institutions"[7], some existing before the adoption of the Convention and others derived from the text adopted in 1982. The legal framework of the sea as established by the Convention covers a broad spectrum: from maritime areas under national jurisdiction (territorial seas, contiguous zones, exclusive economic zones, and the continental shelf) to international areas (the Zone and the seabed). In addition, this system encompasses international regimes and organizations created under the Convention, as well as among diverse state and non-state actors (Treves, 1998). The Convention of the Sea assigns coastal States a series of responsibilities in regarding their maritime areas under national jurisdiction, including conservation and rational management of living and non-living marine resources, navigation safety and marine environment protection in general (Treves, 1998, pp. 327-328). Furthermore, it establishes a legal framework for the peaceful settlement of disputes that may arise in connection with the implementation of the Convention. Thus, according to Treves, "this occurs mainly because several articles establish cooperative actions with existing agencies in fisheries, enclosed and semi-enclosed seas, protection and preservation of the marine environment, marine scientific research and development and transfer of marine technology" (1998, p. 327).

Dispute resolution constitutes one of the more developed areas of UNCLOS, with numerous cases brought before legal bodies and mechanisms to enforce obligations (Sobenes & Loza, 2017; Tanaka, 2012, Chapter 13). An increasingly relevant aspect is its connection with the Paris Agreement and other international commitments since the Rio Summit, particularly regarding climate change (Klerk, 2021). Additionally, States can file cases concerning activities related with the failure to delimit maritime spaces (Liao, 2021).

Costa Rica is among the countries that has implemented the most regulations for the protection of marine resources and has signed various agreements and conventions (Cajiao, 2008). It has also developed public

7 In international relations, the concept of *institutions* refers to three types of entities: sets of rules and behaviors that regulate the conduct of state and non-state actors, international regimes, and international intergovernmental and non-governmental organizations.

policies regarding the seas under its jurisdiction, notably the National Marine Policy and the Strategy for Integrated Management of Marine and Coastal Resources (Comisión Interinstitucional de la Zona Económica Exclusiva de Costa Rica, 2008). These efforts are complemented by specific laws that include provisions related to marine and maritime activities.

Activities of Party States in the instances established by UNCLOS

Regarding the instances established by UNCLOS, this section refers to the Commission on the Limits of the Continental Shelf, the International Seabed Authority, and the International Tribunal for the Law of the Sea. In the first case, those States that consider that they have the right to extend their continental shelf beyond 200 nautical miles (art. 76, par. 8) must submit a request to the Commission, proving their right. This is a complex process that must follow the procedures and scientific-technical guidelines established by the Commission. As of July 17, 2024, 95 applications have been received; however, roughly 50% have only been submitted and are awaiting the establishment of the subcommittee or the issuance of recommendations before being formalized.

On December 16, 2020, Costa Rica and Ecuador were the 86th set of countries to submit a request to the Commission, which was reflected in document CLCS/54/2, dated March 28, 2022. This document records the submission and states that the corresponding sub-commission will be established[8]; marking the result of years of negotiations and bilateral work between political and technical delegations from both countries. For dispute resolutions, the International Tribunal for the Law of the Sea, based in Hamburg, Germany, has handled 33 cases, mostly involving shipping incidents. Instead of resorting to other dispute resolution mechanisms, Costa Rica chose to submit its maritime disputes with Nicaragua to the jurisdiction of the International Court of Justice; this was a matter of preference

8 The executive summary of the joint proposal can be found at https://www.un.org/depts/los/clcs_new/submissions_files/criecu_86_2020/PART-I%20(secured).pdf.

and assessment of results. As for the delimitations with Colombia, Ecuador, and Panama, it has not been necessary to resort to international agencies.

Adoption of the High Seas Treaty

The Agreement under UNCLOS concerning the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction, abbreviated as the BBNJ Agreement, was signed by 88 states on September 20, 2023, and currently has 108 signatories. It represents the most significant step—since the adoption of UNCLOS—in regulating activities beyond the 200 nautical miles of the Exclusive Economic Zone (EEZ). The conventional text (Part VII) was limited to recording customary law (section 1, general provisions) and some relevant rules (section 2) on the conservation and management of living resources in the high seas. The overall objective, according to Article 2, ensures "...the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction, now and over the long term, through the effective implementation of the relevant provisions of the Convention", which calls for enhanced international cooperation and coordination. This step represents a significant advance towards more effective ocean governance, especially in a region where marine resources face increasing pressure that threatens biodiversity and ecosystem health (Hart, 2008). The Ministry of Foreign Affairs and Worship forwarded dossier 24373 for ratification to the Legislative Assembly on June 7, 2024. The explanatory memorandum states that "Costa Rica has demonstrated successful leadership, which has been fully recognized by both the national and the international communities". The bill was transferred to a subcommittee of the Commission on International Relations and Foreign Trade for analysis and recommendation, currently in the consultation phase with institutions and civil society organizations.

A common practice in the Ministry of Foreign Affairs and Worship has been to delay the submission of international agreements to Congress—particularly regarding maritime issues—as was the case with UNCLOS. The longest delays occurred with the 1958 Geneva Conventions, which were approved through laws 4940 (High Seas) in 1971, and 5031 (Territorial Sea) and 5032 (Fishing and Conservation) in 1972.

Selected references to regulatory initiatives on marine and maritime spaces

Law 7291, which approves the ratification of UNCLOS, was issued in 1992 (ten years after its signing). Meanwhile, matters related to transboundary and migratory fish were approved through Law 8059 in February 2001, and with Law 8172 in August 2001, the Agreement on Part XI of the convention was ratified. One pending task in Costa Rica is the adoption of a law to regulate maritime spaces. In January 2011, Bill 17.951 was introduced, but the initiative did not move forward. In July 2012, Decree 37212 was enacted, creating the National Marine Commission. However, in February 2014, Executive Decree 38014 was issued, formalizing the National Marine Policy for 2013-2028 and making the National Marine Commission responsible for articulating, integrating, and reconciling policies on marine affairs. Nevertheless, the frequent turnover of key personnel across different government administrations has led to the discontinuity of these proposals, thus hindering development of comprehensive and long-term strategies for marine ecosystem management.

In June 2019, Decree 41775 was adopted regarding the governance mechanism for marine spaces under the jurisdiction of the Costa Rican State. This decree amended Decree 38014 and repealed other related provisions.

Recommendations

States have the responsibility to ensure effective implementation of the law of the sea in their national jurisdictions. The incorporation of UNCLOS provisions and other related instruments into domestic legal frameworks is crucial to addressing the challenges of protecting the oceans in the Anthropocene era. While States have various rights, they also face increasingly complex obligations and duties —applicable to governments, non-state actors, and the global community— to safeguard marine spaces and ensure the conservation of their living and non-living resources for future generations.

The Costa Rican government, like all States, must conduct a comprehensive review of national legislation related to the law of the sea to implement necessary updates. Of particular urgency are aspects related to the High Seas Treaty, which is progressing slowly in the Legislative Assembly. Therefore, it is recommended that the Ministry of Foreign Affairs and Worship establish a Department of Maritime and Marine Affairs under the Directorate of Foreign Policy. It is essential for this new department to have responsibilities distinct from those of the Department of Borders, Boundaries, and International Treaties—which is currently responsible for preparing documentation for legislative approval of international agreements signed by the country. Specifically, the new department's function should be to "deal with and follow up on border and legal security matters to safeguard national sovereignty".

However, given that 92% of Costa Rica's territory consists of maritime spaces, it is imperative to establish an Institute of Maritime and Marine Affairs. This institute, in coordination with the aforementioned ministry and other government entities such as the Ministry of Agriculture and Livestock (MAG), the Ministry of National Planning and Economic Policy (MIDEPLAN), the Ministry of Public Security, the Ministry of Environment and Energy (MINAE), and institutions like the Costa Rican Institute of Fisheries and Aquaculture (INCOPESCA), should implement marine policies and be responsible for managing marine and maritime spaces. As can be inferred from the above, the law of the sea is a matter of State policy rather than government policy. In many countries -and Costa Rica is no exception- there is no long-term vision on the part of government authorities regarding marine and maritime management. Therefore, the recommendation is to adopt a State policy on Costa Rica's seas, enshrined in legislation rather than just policy documents, to prevent each new administration from discarding the progress made.

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Challenges in the delimitation and expansion of marine areas: the case of Cocos Island National Park, Costa Rica

Rafael A. Gutiérrez Rojas[9]

Since the late 19th century, Costa Rica has been implementing environmental regulations, primarily driven by European researchers such as Henri Pittier, Alexander von Franzius, Karl Hoffmann, and Anders Oersted. With Costa Rican nationals, such as José Cástulo Zeledón, they promoted the establishment of institutions dedicated to natural sciences and the creation of protected areas, mainly to safeguard water resources.

9 Rafael A. Gutiérrez Rojas, former Director of the Sistema Nacional de Áreas de Conservación-SINAC and former Vice Minister of the Environment 2022-2024, rafagutiero@gmail.com

Examples of early regulations include Law 65 of 1888, which recognized lands around the Barva Volcano and Zurquí mountain as inalienable zones, to ensure water resources for the populations in Heredia, Barva and Alajuela (Hilje, 2013). Later, during the 20th Century, at the late 1960s saw the establishment of the National Parks, Wildlife, and Forestry Services under the Ministry of Agriculture and Livestock.

From this moment on, and during the seventies, a process of creation of protected areas began, mainly in the categories of national parks, biological reserves, protective zones, wildlife refuges and forest reserves. During this period in the seventies, the Poás Volcano, Santa Rosa, Cahuita, Tortuguero, and Braulio Carrillo National Parks and forest reserves such as Los Santos, the Central Volcanic Mountain Range, among others, were established (Boza, 2015). In 1978, Cocos Island National Park (PNIC) was established. This island officially became part of Costa Rican territory in 1869, with the goal of protecting marine species and ecosystems, mitigating illegal fishing, and preserving a natural volcanic remnant located about 500 km off the Pacific coast.

Although the 1995 Organic Environmental Law established criteria for the creation of protected areas, the technical parameters were initially broad, leading to inconsistencies in reports regarding the designation or reclassification of protected areas. This issue was addressed in 1998 with the Biodiversity Law, particularly Articles 71 and 72, which set clear parameters for technical studies to establish, modify, or reclassify protected areas.

The technical report includes the objectives for the creation of a proposed area and recommendations on the most appropriate management category, parameters on ecosystem relevance and fragility, wildlife populations, and geological or geomorphological attributes. They also define land tenure status (state, private, or mixed), financial resources for land acquisition (if needed), and the means to ensure long-term protection and management, particularly for legally documented private properties.

A fundamental element to consider in the technical study is the mandatory consultation with indigenous populations or local communities that may affect or have an impact from the establishment or modification of protected areas. Additionally, if a change in management category is proposed, the report must justify the reasons for the change.

In 2008, the Convention on Biological Diversity (CBD) launched a global initiative to identify and map ecologically and biologically significant marine areas (EBSAs) to protect marine biodiversity, considering that in many parts of the world, resources are scarce for technical studies, even with great marine wealth and abundance of highly productive species. Studies conducted around the world indicate that many rare or unique species are found in areas with certain characteristics and, therefore, are sensitive or vulnerable to threats posed by some human activities, especially overfishing and pollution (CBD, 2016).

Influenced by discussions at the Convention on Biodiversity and the interest of governments in strengthening the marine sector, in 2008 the National System of Conservation Areas (SINAC) organized, promoted, and led a study to generate data on ecosystems that were not adequately incorporated into the conservation process and that would serve, in turn, to delineate management mechanisms for protected areas. Thus, the "Land Use Planning Proposal for Biodiversity Conservation in Costa Rica" was created, known as GRUAS II, since there had been a previous study along the same lines that had not considered the country's marine or riverine areas. This project included an analysis called "Gaps in the Representativeness and Integrity of Marine and Coastal Biodiversity", which was the first effort to identify important sites for conservation in Costa Rica's marine and coastal areas.

This analysis has guided the country towards establishing strategies for the attention and incorporation of marine and coastal sites into the national system of protected areas, through different management mechanisms and management categories. For example, marine management areas such as Montes Submarinos, Cabo Blanco, Santa Elena, and Barra de Colorado have been included, which promote both conservation and responsible use of marine resources. Existing areas with strict categories have been expanded. This study revealed the lack of zoning, planning and management mechanisms for Costa Rica's marine environment; a finding that raised awareness of the importance of marine zoning to facilitate the management, use, and conservation of the country's marine resources (SINAC, 2008).

One of the main conservation gaps identified in GRUAS II was Cocos Island and the Cocos Submarine Mountains, as their existing boundaries did not fully encompass key ecosystems. Although formally declared with proper legal mechanisms (such as executive decrees and national laws) before the year 2021, these do not include all sites of environmental interest within their boundaries, as indicated by technical and scientific studies based on representative data from the entire Exclusive Economic Zone (EEZ) of the Costa Rican Pacific Ocean, as well as findings from regional initiatives, which had identified the need to expand these protected areas, whose special interest was to ensure conservation of endemic, resident and pelagic species of marine and insular fauna and flora and maintenance of the ecosystem services they provide. The study guided SINAC's actions in two directions: to seek mechanisms with other institutions to promote marine management and to expand existing areas to incorporate ecosystems of biological value.

Expansion Process of Cocos Island National Park and Montes Submarinos Management Area Under the Directorate of the Cocos Island Marine Conservation Area collaborating with environmental organizations, international cooperation and its own resources, specific technical studies were initiated in 2017 to provide baseline information for supporting or rejecting boundary expansion or adjustment of Cocos Island and Montes Submarinos protected areas. Among these studies are:

a. *Importance of the ecosystems and populations within the area of interest: Cocos Island National Park, the Montes Submarinos Marine Management Area, and adjacent waters of the Cocos Marine Conservation Area.*

b. *Economic valuation of ecosystem services in the Cocos Marine Conservation Area and Adjacent Waters.*

c. *Estimation of visitors' willingness to pay an additional amount, beyond current expenses, for the potential expansion of ecosystem and species* *protection in the Cocos Marine Conservation Area and its adjacent waters. Estimation of fishery biomass in the Costa Rican Exclusive Economic Zone and areas of interest within the Exclusive Economic Zone.*

d. *Estimation of fish biomass in Costa Rica's Exclusive Economic Zone and areas of interest within this zone.*

e. *Estimation of fish biomass in the Cocos Marine Conservation Area and surrounding waters, along with predictions of species landing probabilities based on bioclimatic conditions.*

f. *Characterization of the longline fishing fleet in Costa Rica.*

g. *Prioritization for zoning Costa Rica's Pacific Exclusive Economic Zone based on conservation objectives and uses, along with a technical report.*

These studies, together with criteria from experts and SINAC-ACMIC staff, identified key conservation gaps for ecosystems and species in the Cocos Island and Montes Submarinos region.

Cocos Island National Park: characteristics and challenges

Since the declaration of Cocos Island as a national park in 1978 by Executive Decree No. 8748-A, which was later ratified by Article 1 of Law No. 6794, the category of "national park" was identified as the most appropriate model for conserving its biodiversity and associated ecosystems. Subsequent studies confirmed the well-preserved state of these ecosystems and their ecosystem services, highlighting the distinct conservation benefits provided by designated protected areas compared to adjacent unprotected areas.

According to protected area management methodologies promoted by the International Union for Conservation of Nature (IUCN) and adopted by Costa Rica, protected areas plan their development, management, and administration with a methodology of focal conservation elements, based on the most representative natural and cultural attributes, as well as on those components of biodiversity that are endangered or vulnerable. In the case of Cocos Island National Park (PNIC), this methodology has been applied to identify the following focal management elements (FME) in its General Management Plan: reef formations, geological formations (specifically pinnacles and islets), pelagic species (sharks, rays, and marlins), island forests, and historical cultural heritage (SINAC, 2013).

Studies also indicate that some of the species identified in the Cocos Island protected area and defined as conservation targets are highly migratory, which makes them vulnerable when they leave the protected area (Arauz *et al.*, 2014). Likewise, it has been recognized that geological formations such as pinnacles and seamounts, some of great biological importance, are currently unprotected, despite being essential ecosystems to ensure ecological processes for most of the marine species considered as focal management elements.

According to global and regional studies, ecosystems like the Seamounts contribute significantly to marine fauna diversity and abundance, maintaining complete food chains and their ecosystem services. After analyzing the results of technical studies and discussing the conservation status of Cocos Island species and ecosystems, as well as the feasibility of its long-term maintenance, it was concluded that expansion of the geographic area declared as national park is both urgent and necessary. This will ensure maintenance of ecological processes in the area. It was identified that stricter ecosystem protection measures should be implemented, permitting only indirect uses such as low-impact ecotourism, research, and environmental education. These measures aim to reduce the impact on the fragile ecological processes and mitigate species decline, among other potential issues.

The expansion of the PNIC should ensure the representation of vulnerable ecosystems and species, particularly pelagic species and geological formations. In addition, it should lay the foundation for efficient management and administration, protecting focal management elements and promoting their responsible use to strengthen groups involved in national park management (SINAC, 2021).

Montes Submarinos Marine Management Area: characteristics and challenges

According to Article 70 of the Regulations to the Biodiversity Law No. 34433, the main objectives of marine management areas are a) to guarantee the sustainable use of marine-coastal and oceanic resources; b) to conserve ecosystem, species, and gene biodiversity; and c) to maintain environmental services, as well as cultural and traditional attributes.

In the case of PNIC and the Montes Marinos Marine Management Area (AMMMS), technical studies have indicated that associated ecosystems and species are highly vulnerable and many are unprotected. This is particularly true for seamounts and pinnacles, which are crucial for conserving ecological processes and facilitating marine migration. This migration plays a key role in partially connecting -under conservation frameworks- the marine protected areas within the Eastern Tropical Pacific Marine Corridor. Therefore, incorporating new ecosystems is essential to fulfilling the provisions of Article 70 of the Regulations to the Biodiversity Law.

Since expanding a marine management area of this kind, and its associated ecosystems, would involve a considerable extension of ocean space, efforts were proposed to strengthen the necessary management processes in alignment with both existing and potential future management objectives. This is essential to reduce pressures on marine resources, both within this protected wildlife area and within the PNIC, since this area is a buffer zone for the park. Additionally, different groups have been particularly interested in using natural resources for tourism, research, and fishing in the studied area. This brought to light the need to establish management regulations that would benefit different sectors without threatening resource integrity.

Considering previous studies and analysis, the expansion of AMMMS was deemed necessary to protect sensitive resources, vulnerable species, and migratory corridors, in addition to promoting sustainable uses that benefit of communities and stakeholders. The importance of establishing effective governance mechanisms was also emphasized, along with strengthening the joint actions undertaken by Costa Rica since 2001 through regional agreements for the creation of the Eastern Tropical Pacific Marine Corridor. This expansion aligns with Costa Rica's commitment to the Convention on Biological Diversity and its efforts to meet the 2030 Sustainable Development Agenda.

Consultation process

This process includes several scenarios and stages aimed at encouraging participation of relevant groups and stakeholders in possible results of PNIC and AMMMS expansion. Between March and July of 2021, the first phase of the process took place, consisting of approximately 20 working meetings to gather opinions and perspectives from participating groups regarding the possible expansion of the afore mentioned protected areas. In addition, the process sought to determine the technical, financial, and legal feasibility of the proposal. Participants included representatives from academia, government institutions and the productive, tourism, and fishing sectors. The discussions covered topics such as the international agenda, international environmental commitments, commitments to donors and international cooperation, as well as environmental, economic and community well-being.

Some of the results of the process were the importance of seeking partial agreements, the need to understand and address the interests and needs of different groups and conditions for future governance, among other aspects. The second phase consisted of multisectoral roundtables held between July 20 and 23, 2021. These roundtables were carried out with participants from government, academia, environmental NGOs, fisheries, and tourism sectors. The discussions were planned using a uniform methodological approach to ensure comparable results across different sessions. A total of 70 participants from different sectors were divided by sector and area of interest.

In these sessions, some sectors expressed their disagreement with how information and prior consultations were handled; therefore, additional sessions were held, both with the fishing sector, to consider information on fishing activity to improve the proposal, and with a group of experts, to provide technical feedback on the analysis of scenarios related to the expansion of the PNIC and AMMMS. Finally, a plenary session was held to present the results and propose criteria for possible modifications to the expansion proposal, including a new orientation of the expansion polygon toward the south. Certain groups insisted that a consensus had not been reached, and that the consultation process needed to be extended. Thus, MINAE-SINAC, as the entity responsible for the administration of protected areas, together with other governmental agencies, convened additional working groups that would be a third phase of consultation, which took place between October 15 and November 12, 2021, in the city of Puntarenas: a place chosen to facilitate access of various groups from the fishery sector to the discussion tables.

Each of these roundtables were attended by approximately 50 people from 23 different organizations, including representatives of civil society organizations, mainly from the productive sector and academia. At the end, an extension proposal was prepared and a file with the technical basis was uploaded to MINAE's web page to obtain inputs and comments, which were analyzed by technical teams. Relevant suggestions were included in the final proposal and the others were discarded.

Even though a consultation process was carried out at various levels and with different sectors, there was opposition, mainly from some fishing groups, which generated a subsequent counterargument from MINAE-SINAC, the entity responsible for the process of expanding the marine areas.

Among the objections raised by these groups was the claim that the government had not provided sufficient access to information. However, it was clarified that all relevant information had been made available on the institution's website for public access. Another argument was that marine protected areas prohibit fishing. In response, it was explained that regulated fishing is permitted within marine managed areas, except in zones designated as national parks. Furthermore, opposing sectors also stated that declaring close to 30% of the territorial sea as marine areas was excessive and that Costa Rica already had protected around 46% of its sea. However, authorities clarified that marine protected areas should not be equated with fishery management measures, such as tuna fishing polygons, meaning that Costa Rica did not actually have such high levels of marine resource protection. The groups also stated that the proposal could put many people out of work, but it was counter-argued that there are no studies to support this assertion. On the contrary, global evidence indicates that protecting marine areas can create better fishing conditions due to factors such as spillover effects and increased species abundance within protected areas. Additionally, the tourism industry is a growing sector that thrives in well-protected natural spaces. Finally, it was argued that the designation of such a large, protected area would force fishing activities to concentrate in a much smaller portion of Costa Rica's territorial waters. However, it was clarified that fishing fleets would still have access to 70% of Costa Rica's marine territory without protected areas and that regulated fishing is permitted within the marine managed area.

Technical proposal

After conducting the respective technical studies and executing the different stages of public and technical consultation, a proposal was formulated for the expansion of the PNIC and the Bicentennial AMMMS. This proposal integrated conservation gaps identified in previous studies, recommendations of various technical analyses, and information provided by several stakeholders during the consultation process. It also included the protection of previously identified key management elements.

For the technical expansion proposal, the conservation spatial prioritization tool known as Marxan (Ball *et al.,* 2009) was used, based on the simulated annealing algorithm. This methodology, widely applied worldwide, identifies complementary sites to achieve efficient implementation of specific conservation targets while minimizing the socioeconomic costs that conservation measures might impose on users in the marine sectors included in the expansion process. Furthermore, priority conservation areas were established within the Exclusive Economic Zone to assess the significance of sites in areas adjacent to the PNIC and the AMMMS. This analysis was conducted using data provided by various institutions (Figure 2.1).

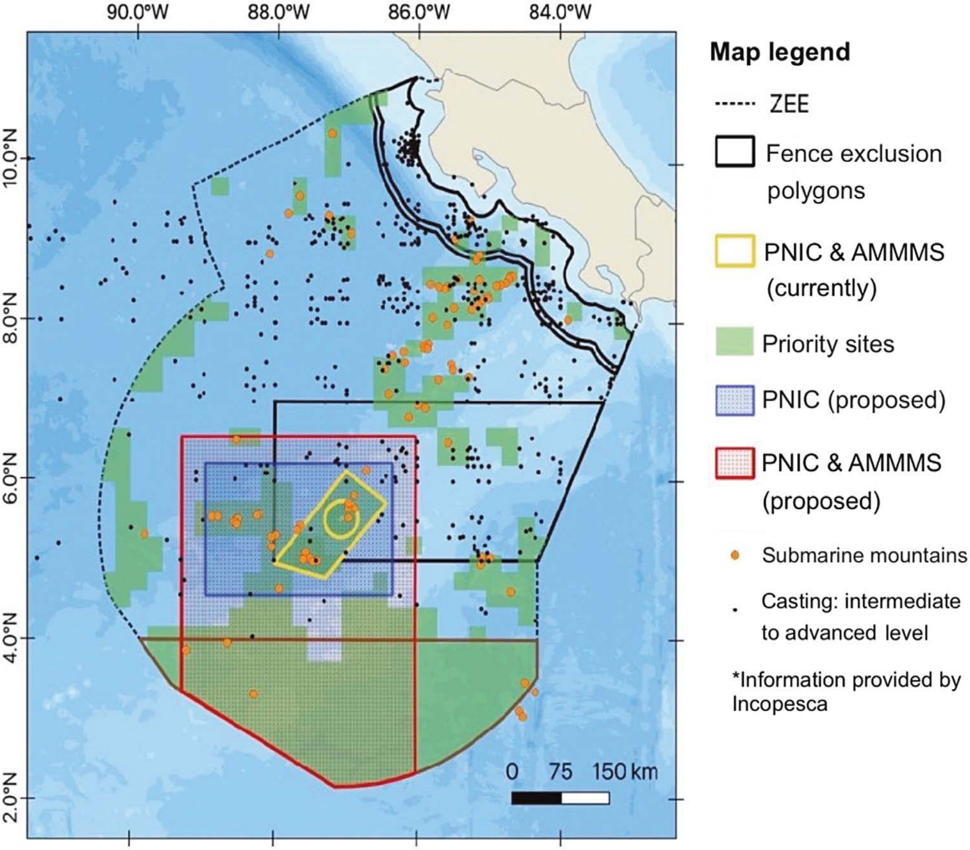

Figure 2.1. Proposed Expansion of Cocos Island National Park (PNIC) and Montes Submarinos Bicentennial Marine Management Area (AMMMS) and priority conservation sites.

Source: SINAC-ACMIC, 2021.

Controversy

Following the consultation process, the Executive Branch accepted the technical proposal and issued Executive Decree No. 43368-MINAE, proposing the expansion of the PNIC from 1997 km^2 to 54,913 km^2 and the Bicentennial AMMMS from 9,649 km^2 to 105,063 km^2, for a total of 159,976 km^2 for both protection areas. This measure ensures the protection of a significant portion of Costa Rica's Exclusive Economic Zone, representing the most extensive protection for pelagic species that move across different areas and locations within the Eastern Tropical Pacific. Additionally, it safeguards sensitive ecosystems, such as underwater mountains and pinnacles, many of which are critical hotspots of productivity. Moreover, it helps preserve numerous endemic, resident, and migratory species that face varying degrees of vulnerability due to human activities and enhances a site of high interest for responsible tourism.

The expansion of these two protected wildlife areas led to submission of an unconstitutionality action before the Costa Rican Constitutional Court, which was accepted for study and resolved on April 17, 2024. The Court unanimously rejected the arguments presented, accrediting among other things that a consultative process was carried out prior to issuance of the executive degree. Furthermore, the analysis found that technical studies had confirmed a specialized foundation for greater protection to the PNIC and the Bicentennial AMMMS, respecting the principle of rationality (Chacon V., *Semanario Universidad*, April 24, 2024). The Constitutional Court's ruling, along with the procedures followed by the responsible institutions, both MINAE and SINAC, and the Cocos Island Marine Conservation Area, serve as an example of how to review protected area boundaries and, in some cases, how to propose expansion or revision of management categories to change them. This process was conducted with care and in compliance with national legislation to properly address disputes among different sectors.

It is important to emphasize the necessity of technical studies to support decision-making. These processes typically take years and can be costly, requiring proper budgeting and mid-term planning. Equally significant is public participation and the implementation of consultation processes that allow space for different sectors and stakeholders, even when there are differences in opinion. In most cases, due to the specificity and complexity of the subject matter, the processes should be accompanied by experts. On the other hand, it is important to look for governance models where different groups can participate in decision-making and administration of protected areas, especially those that allow for rational use of resources, such as marine management areas, because it strengthens interest of the different groups and generates benefits for stakeholders. Expanding protected areas entails technical and financial commitments that must be met to address management responsibilities and the ecological impacts of climate change. Costa Rica's experience demonstrates that international cooperation and environmental donors have been crucial in promoting management and administrative processes for protected areas together with the Executive Branch. For this reason, conservation areas and SINAC must strengthen these processes, as they have proven to be beneficial in addressing the complex challenges of managing Costa Rica's environmental protection system.

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Small-scale fishing and marine conservation: towards a human rights approach and compliance with international commitments

Marvin Fonseca Borrás[10]
Vivienne Solís Rivera[11]

Costa Rica has built a State that guarantees a set of constitutionally enshrined individual and collective rights. In addition, it has established itself as a country that recognizes multi-ethnic and cultural differences, thanks to its Political Constitution (Articles 1, 7, 33, 50, 73 and 74). Likewise, it has built a robust scaffolding that, from the Executive Branch, allows implementation of necessary actions to guarantee effective coexistence, opportunities, social security, and the distribution of wealth. Despite this constitutional aspiration and the

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institutional development, there are gaps in some sectors of the country's population. This limits opportunities for certain individuals, such as people associated with small-scale artisanal fishing.

International progress towards defending the rights of small-scale fishers

The Human Rights Council, a United Nations intergovernmental body responsible for strengthening the promotion and protection of human rights (55th session-A/HRC/55/49-2024) stressed that small-scale fishing is more a social, cultural and political activity than a technical one, and that States must ensure public and transparent processes to address the persistent marginalization and political exclusion of small-scale fishing communities, considering the impacts of blue economy and climate crisis. This implies, among other elements, active and free participation in the decision-making process related to preparation and implementation of policies, programs and projects that affect their lives; as well as the adoption of measures to combat gender discrimination, social protection and decent jobs, land and marine tenure rights, fishery management, access to health systems, education, food security, among others.

Diverse United Nations bodies have approved binding international instruments that have been ratified by the Government of Costa Rica and whose aim is to recognize the contribution of small-scale fisheries from a human rights perspective, such as the Universal Declaration of Human Rights, the United Nations Convention on the Law of the Sea (1992), the United Nations Fish Stocks Agreement (1995), the Convention on Biological Diversity (1992), the Convention on Indigenous and Tribal Peoples in Independent Countries, Convention 169 (1989), and the United Nations Declaration on the Rights of Indigenous Peoples (2007). In addition to these instruments, governments that are part of the World Food and Agriculture Organization (FAO) have signed other non-binding instruments that also instruct institutions to advance in this sector under a human rights framework, such as the Voluntary Guidelines for Achieving Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (VGFS), approved by the FAO Committee on Fisheries (COFI) in 2014, and signed in the country by Executive Decree No. 39195 MAG-MINAE-MTSS-2015.

Despite these advances, decision-making has been primarily focused on a vision of preserving ocean biodiversity, marine conservation, science, technology, and the blue economy, with limited participation of small-scale fishers in the international concert and global decision-making (Figure 3.1). Recently in 2022, with the aim of influencing international fora promoted by the United Nations, national, regional and interregional organizations representing small-scale artisanal fisheries around the world, from Africa, the Pacific, Asia, Europe, South America, and Mesoamerica, have submitted two documents to international authorities that outline the sector's main demands: A Call to Action for Small-scale Artisanal Fisheries, and the Codes of Conduct for Working with Artisanal Fishers and Small-Scale Fishery Workers to Save our Ocean.

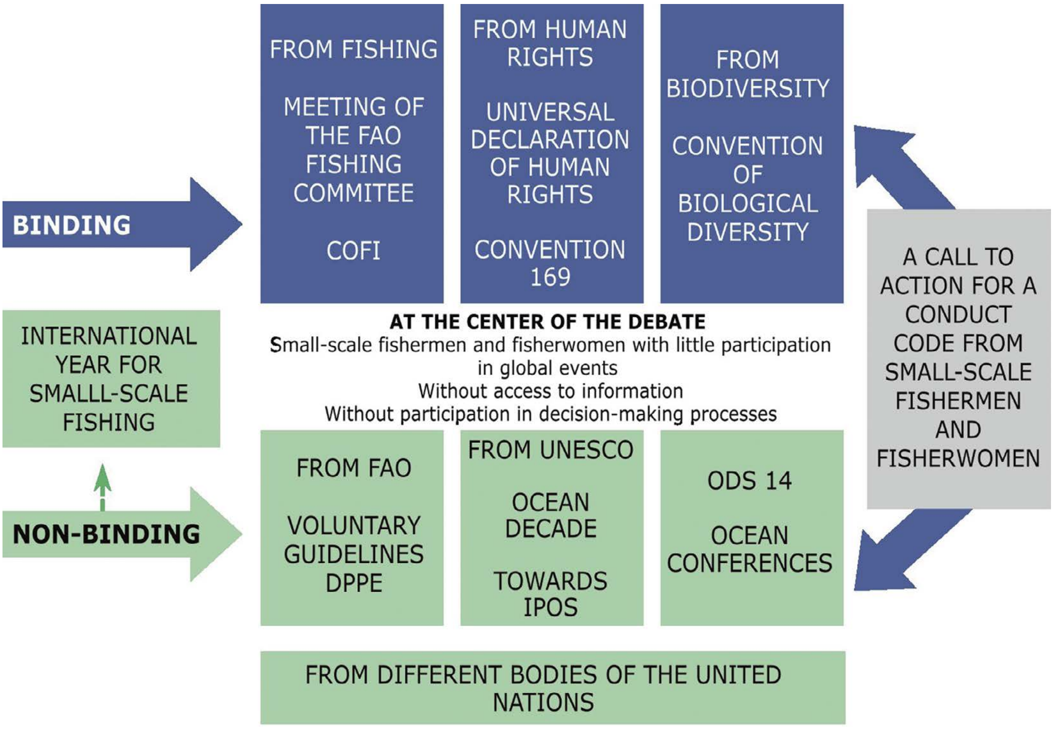
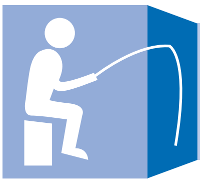


Figure 3.1. A complex international landscape with limited opportunities for small-scale fishery representatives.

Source: Own elaboration.

Situation of small-scale fishing in Costa Rica

As dictated by national legislation, different institutions are responsible for conservation, promotion, fisheries control, and preservation actions. Marine exploitation also falls under their responsibility. Therefore, an integrated management of marine areas is a complex endeavor. The Ministry of Agriculture and Livestock (MAG), through the Costa Rican Institute of Fisheries and Aquaculture (INCOPESCA), oversees commercial fishing species and fisheries promotion. Meanwhile, mangrove ecosystems are under the jurisdiction of the National System of Conservation Areas (SINAC), as established in Organic Environmental Law No. 7554, while permits for mollusk harvesting are the responsibility of INCOPESCA, according to a study endorsed by SINAC. On the other hand, marine control and surveillance issues are the responsibility of the National Coast Guard Service of the Ministry of Public Security; and in marine protected areas, control and surveillance is the responsibility of MINAE/SINAC. According to Law 8436 on Fishing and Aquaculture (LPA)/2005, the small-scale fishing fleet is composed of artisanal fishing, small-scale commercial fishing, and fishing for domestic consumption, defined respectively as:

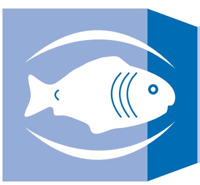


Artisanal fishing

Fishing activity carried out in an artisanal or small-scale manner by individuals using a vessel in inland waters or coastal areas, with an operational autonomy of up to five nautical miles from the shore and conducted for commercial purposes. (LPA, article 2, paragraph 26).

Small-scale commercial fishing

Fishing carried out in an artisanal manner by individuals, without the use of a vessel, in inland waters or coastal areas, or practiced on board a vessel with an autonomy to fish up to a maximum of three nautical miles within Costa Rica's territorial sea (LPA, article 2, paragraph 27a).



Domestic Consumption Fishing

Fishing for home consumption is understood as that which is carried out from land or in small boats, using only rods, reels, or hand lines, with no commercial purpose, and solely for self-sustenance or family consumption (LPA, Article 77).

In social and productive terms, the situation of small-scale artisanal fisheries is complex. Based on CoopeSoliDar R.L. (2023) and the State of the Nation Program (2022), the following is outlined:

1. **Governance:** The Law on Fishing and Aquaculture (LPA) proposed that the State shall provide financial, health, safety, and social welfare support to all persons engaged in fishing and aquaculture activities (LPA, Article 170). According to the spirit of the LPA, there is an institutional responsibility to comprehensively look after the fishing sector and its productivity, which has not been fully complied with.

2. **Registration of the small-scale artisanal fishing sector:** the country does not have a fishing census or robust data that would allow precise quantification of people in this sector, a situation that makes it impossible to estimate a budget or institutional attention or even to generate public regulations that would allow addressing small-scale sector structural problems.

3. **Recognition of women in small-scale fishing activities:** fishing activities have been considered only as "men's work". However, studies conducted by CoopeSoliDar R.L. (2019) show that women fishers and mollusk gatherers carry out around 25 key tasks for small-scale fishing that are not recognized, which makes women's contribution to the production chain invisible: pre-fishing, fishing, and post-fishing.

4. **Decent and dignified jobs:** The right to work is enshrined in the Political Constitution. Given the gaps in scientific information and demographic data linked to small-scale fishing activities, the Costa Rican State has not been able to guarantee the right to decent and dignified jobs for this productive sector. As a result, the small-scale fishing sector develops informally and without documentation.

The Comptroller General of the Republic, through official letter DFOE-EC-IF-14-2012, dated November 27, 2012, highlighted the need for scientific and technical studies of the artisanal fleet to grant licenses. Since then, INCOPESCA has not issued licenses, leaving most small-scale artisanal fishers in an informal status (Contraloría General de la República, 2012).

According to Article 104 of the LPA, INCOPESCA is responsible for administering the issuance of licenses, authorizations, permits, and concessions, as well as their extensions, according to the previous study carried out by INCOPESCA or MINAE, depending on the case. From a human rights approach, the lack of information and studies as an impediment for the issuance of fishing permits is also a questionable element. For instance, the issuance of a sport fishing license does not require the scientific studies that are mandated for small-scale fishing. adding to the complexity, the Ministry of Labor and Social Security (MTSS) does not include any salary category or occupation related to small-scale artisanal fishing. In 2020, because of a consultation carried out by FAO, the MTSS presented the results of a study of job occupations related to fishing activities. The research recognized that the institution has not made any adjustment of occupations in 20 years and recognizes the activity: fishing laborer or artisanal fisherman laborer, classified as an unskilled worker; artisanal fisherman (boat captain), classified as a semi-skilled worker; shrimp peelers and shellfish gatherers, classified as unskilled workers. The National Wage Council, in its ordinary session No. 5616, agreed on the intention to review and update this document, mainly in view of the National Qualifications Framework.

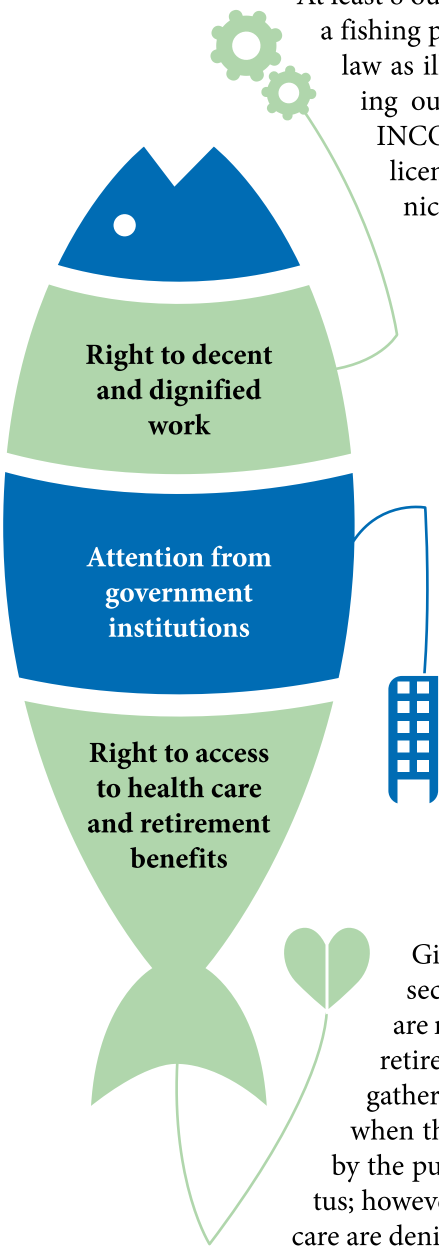
5. **Social development:** according to the Social Development Index (MIDEPLAN, 2023), the Social Progress Index (CLACDS-INCAE, 2024), and the Cantonal Human Development Atlas (UNDP, 2023), coastal areas are the geographical areas with the highest social deterioration and lowest human development indexes in Costa Rica. The information provided by these indexes reflects the need to advance as a country in compliance with international treaties and current national regulations. This orientation guarantees conditions that

allow this sector of the population to have basic opportunities for education, health, and work, fundamental pillars from a human rights approach. The lack of official information on the population associated with small-scale fishing is a form of violence leaving people linked to the sector vulnerable, as it makes it impossible to develop public policies or granting of budgets that can meet their needs. In this context, women involved in small-scale fishing are the most affected population group, as their work is largely invisible in relation to the contribution made by men. Additionally, the absence of land tenure rights and formal access to marine resources leads to displacement and migration, preventing these populations from settling and developing in coastal areas. This situation particularly affects young people, who lack real development opportunities in their coastal territories—an issue that benefits other economic sectors, such as tourism and real estate.

Concrete cases of infringement of the rights of small-scale fishers

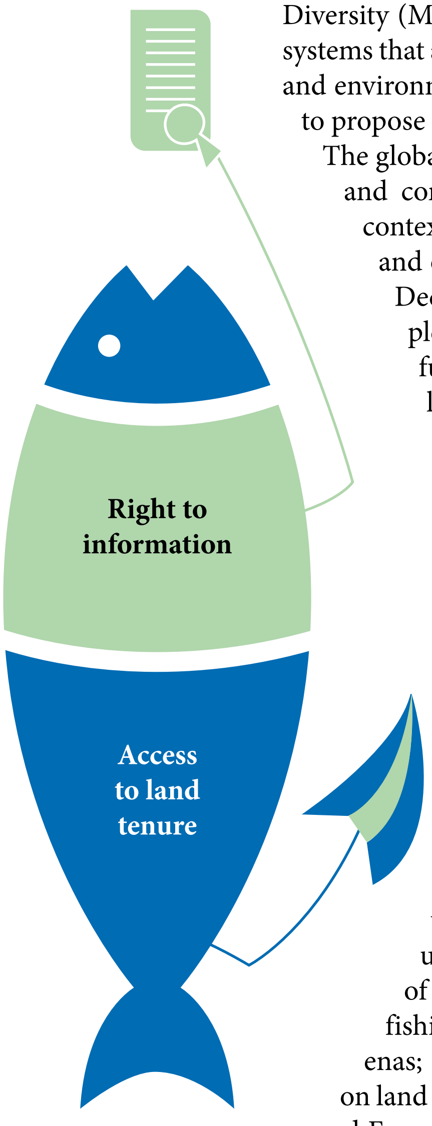
According to estimates presented in PEN (2022), the small-scale fishing sector involves around 16,000 individuals; the same report mentions the participation of about 30,000 individuals. The following are some of the main impacts affecting the small-scale fishery population:

At least 8 out of every 10 small-scale fishers do not have a fishing permit, which places them in the eyes of the law as illegal. This criminalizes most people carrying out this activity. The Government, through INCOPESCA, is responsible for granting fishing licenses, an administrative act justified on technical studies of the available fishing biomass.



Government institutions do not have official and updated statistics on the people who live directly or indirectly from small-scale artisanal fishing activities. Due to this lack of registration, government institutions address this population based on their poverty status rather than their employment activity, which is one of the reasons why the government's social welfare programs cannot address the social and economic issues faced by this population.

Given the informal nature of the small-scale sector, most fishermen and shellfish gatherers are not included in the country's health care and retirement system. Women fishers and mollusk gatherers have accessed the right to health care when their partner has insurance or when covered by the public health system due to their poverty status; however, those women who have access to healthcare are denied the right to retirement benefits.



In recent years, as a result of agreements made in the Kunming-Montreal Global Framework for Biological Diversity (MGB) (CBD, 2022), to preserve marine ecosystems that are important for biodiversity, governments and environmental organizations have increased efforts to propose the creation of new protected marine areas. The global goal is to conserve at least 30% of marine and continental protected areas. In the national context, the right to information, consultation, and objection, enshrined in the United Nations Declaration on the Rights of Indigenous Peoples and in Convention 169, have not been fully complied with in the process of establishing marine and inland protected areas. Thus, in many cases of creating protected areas or expanding marine protected wilderness areas, small-scale artisanal fishers have not had the necessary information on the impacts of conservation measures.

A frequent problem is that fishing communities and their collection centers are in marine-coastal zones, within 200 meters (public zone: 50 meters from high tide, restricted zone: the remaining 150 meters). As a result, fishermen and fisherwomen do not have recognition of land tenure rights, which increases the vulnerability of these communities. Some examples are the fishing villages at the pier in Tambor, Puntarenas; the Barra de Colorado community, settled on land owned by the Board of Port Administration and Economic Development of the Atlantic Coast of Costa Rica (JAPDEVA); and the Chomes community mollusk gatherers, most of whom have established their homes in the mangrove swamp.

Positive examples of small-scale fishers' rights defense

In recent years, attempts have been made towards generation of public policies to provide answers to the critical situation experienced by small-scale fishermen and shellfish gatherers, as identified below:

Responsible Fishing Areas: In 2009, Executive Decree 35502/2009 recognized the category of Responsible Fishing Marine Area, which is a measure of fishing exploitation and biodiversity conservation based on a marine area that guarantees the right to fish and participate in the decision-making process by small-scale fishermen and women, through a model of governance and shared management. This is done according to a Fisheries Management Plan (POP) prepared jointly by representatives of the fishing community requesting the area and INCOPESCA's technical team. Once approved by INCOPESCA's Board of Directors, the marine area is recognized. There are currently 13 Responsible Fishing Marine Areas on both coasts of the country.

Contributions in the struggle for human rights led by the Network of Responsible Fishing Areas and Marine Territories of Life (La Red).

La Red is an initiative that started in 2004 with representatives of small-scale artisanal fishermen and fisherwomen, with the objective of raising a voice for this sector. In 2015, it was consolidated as an open group composed of representatives from local, Afro-descendant, and Indigenous communities, as well as small-scale fishers and mollusk gatherers. Their collective effort focuses on defending rights and addressing the structural issues faced by the small-scale fishing sector. At present, the Network includes 22 communities and is estimated to directly and indirectly involve around 7,000 people.

La Red has organized three national congresses for small-scale fishers. As a result, three declarations have been drafted to address the main structural issues in the sector. These declarations are key to defining a roadmap for future work (see citation links for the declarations).

La Red also supported the drafting and approval of Executive Decree No. 39195 MAG-MINAE-MTSS/2015, which enforces the Voluntary Guidelines to Achieve Sustainability of Small-Scale Fisheries in the Context of Food Security and Poverty Eradication. This decree was a significant step forward in terms of recognition of fishing activities from a human rights approach. However, government institutions have failed to implement it, which constitutes a constitutional violation.

La Red also contributed its expertise to Executive Decree No. 42955-MAG/2021, "Declaration of public interest of the development model of the small-scale artisanal fishing sector contained in the public-private alliance for small-scale fishing in responsible fishing marine areas and marine territories of life" (known as the 12 Oars Model). This regulation defines a strategy for the continuous improvement of small-scale artisanal fishing and shellfish harvesting organizations, based on a human rights approach that starts from the recognition of the people involved in the activity. This model eliminates the bias of criminalization of the activity (illegal fishing), allowing government institutions, starting with INCOPESCA, SINAC/MINAE, and the National Coast Guard Service, to work progressively with the fishing community (PEN, 2022).

Recently, Network representatives formulated a draft called: "General Law for the Sustainability of the Small-Scale Artisanal Fishing Sector". After a period of adjustment for observations from the Legislative Assembly's legal team and further consultation with small-scale representatives in the year 2023 (from Puntarenas, Caribbean and South Pacific), negotiations have taken place with legislative representatives from fishing provinces to ensure the bill is promptly discussed in Parliament.

Executive Decree No. 39195 MAG-MINAE-MTSS (2015), Executive Decree No. 42955-MAG (2021) and the proposed bill have been prepared in accordance with the DPPE, approved by FAO-COFI, 2014. These three legal instruments aim to address the structural problems faced by the small-scale sector and require institutions to comply with current regulations.

Conclusions

The country has regulations (constitutional, international treaties approved by the Legislative Assembly, executive decrees, and voluntary instruments) in place to promote a comprehensive approach to the small-scale fishing sector. However, institutional management has not addressed the issues faced by individuals in this sector with an integrated or human rights-based approach. No progress has been made with respect to the rights of this population, such as the right to work, land tenure, access to the sea, health, and retirement. Likewise, there have been violations of the right to information, consultation, and objection in the processes of establishing marine protected areas, as recognized in the United Nations Declaration on the Rights of Indigenous Peoples, Convention 169, and the Convention on Biological Diversity. This situation, combined with government and private sector efforts to promote an unsustainable blue economy, is generating unjust and inequitable development along the coasts.

Recommendations

The Costa Rican government must adopt a differentiated approach to the small-scale fishing sector. To achieve this, a roadmap must be defined under a human rights framework that includes:

- Ensure the implementation of Executive Decree No. 39195 MAG-MINAE-MTSS, "Official application of the Voluntary Guidelines for achieving sustainability of small-scale fisheries in the context of food security and poverty eradication".
- Require INCOPESCA to implement Executive Decree No. 42955-MAG "Declaration of public interest in the development model for the small-scale artisanal fishing sector contained in the public-private alliance for small-scale fishing in responsible fishing marine areas and marine territories of life" (12 Oars Model).

- Take the necessary steps to ensure that the Legislative Assembly approves and enacts the "General Law for the Sustainability of the Small-Scale Artisanal Fishing Sector".
- That government institutions and non-governmental environmental organizations, address the statements made by representatives of small-scale fisheries in global forums before United Nations authorities and government representatives: a) A call to action for small-scale artisanal fisheries; b) Codes of conduct for working with artisanal fishers and small-scale fishery workers to save our ocean.

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Coastal social vulnerability and Costa Rican institutional framework: evidence for improving state and local agency capacity

Mario Hernández Villalobos[12]

Along the coastlines of Costa Rica (approximately 450 km on the Pacific Ocean and 200 km on the Caribbean Sea), there are 816 localities, distributed in 70 districts, according to the current political-administrative division. These populations experience the highest levels of social vulnerability, understood as the condition of a population in a state of inequality compared to other groups, which exposes them to greater hardships due to the reduction of necessary resources (material, human, and governmental) needed to address everyday societal

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challenges. This vulnerability is further exacerbated by exposure to environmental conditions specific to coastal areas, including events linked to climate variability and climate change, which can sometimes be adverse (Hernández, 2023).

This social vulnerability also stems from a systematic governmental neglect, which hinders the effective implementation of public policies and fails to promote the inclusion of these areas and their populations in state initiatives. As a result, this issue significantly limits the possibilities for comprehensive human development.

On the other hand, the Costa Rican State consists of a conglomerate of public organizations forming an uncoordinated institutional framework, with 45 entities operating under 42 administrative acts and eight laws (Hernández *et al.*, 2021). This lack of coordination was identified by the administration that, in 2013, promoted the National Maritime Policy to address the disorderly governance of marine-coastal zones and their populations. However, this public initiative has not generated policy actions that mitigate the identified problems.

The scope of the Interdisciplinary Coastal Program (ICP) is achieved through the definition of its specific objectives, related to applied socio-environmental research, observation processes and critical analysis of public policy related to coastal zones and populations. Additionally, it seeks to strengthen local grassroots coastal organizations through participatory social support techniques.

The contrast of these findings with the current competencies and functions of public organizations related to coastal issues made it possible to achieve the objective of this contribution: to highlight the absence of a comprehensive public policy framework addressing coastal social issues. This topic is approached from the ICP of the Instituto de Estudios Sociales en Población (Idespo) at the Universidad Nacional, Costa Rica, where various research and university extension processes have been carried out for 24 years in the Gulf of Nicoya, and more recently in the southern eastern Pacific and southern Caribbean regions of the country, with the intention of contributing to the well-being of coastal populations and the transformation of their realities towards better living conditions.

As part of ICP's research activities, two studies were conducted: one on Costa Rican institutions in coastal management and the other on Costa Rican coastal social vulnerability (Hernández *et al*., 2021 and Hernández, 2023, respectively). The findings and conclusions from these studies are used in this document to emphasize the absence of a comprehensive public policy framework addressing coastal social issues. Additionally, the research highlights the importance of promoting local coastal capacities to compensate for this gap in the relevant institutional framework.

State and local agency capacity

The social vulnerability of coastal populations is a condition resulting from a historical and systematic state neglect of the issues affecting these communities, stemming from a deficient capacity of state agency. The term "capacity" is defined by the Royal Academy of the Spanish Language as "the quality of something or someone to be capable of executing the action that is expressed"; given the above, we can say that in democratic state regimes this implies formulating and effectively executing public policies, linked to the institutions and public organization of said regime. The "state capacity" (as such) has been explicitly conceptualized since 1968 in diverse research on political science and public administration (Huntington, 1968 cited by Cingolani, 2013). Meanwhile, Bertranou (2015) defines state capacity in terms of achieving the purpose set out in each public organization that makes up the State, which is based on improving the living conditions of the population. This pursuit of improvement is supported by human resources, legal competencies, legitimacy, and organizational and inter-organizational action resources, which drive public policies, which are not exempt from power dynamics.

A rational state administration of public policies, with a focus on addressing the most vulnerable sectors, leads to an increase in governmental capacities. This, in turn, would enhance the efficiency of public policies and, consequently, the execution of public spending (Scartascini and Tommasi, 2014). In this way, the opportunities that the State grants to citizens through its institutional framework determine the participation of coastal leaderships in territorial decision-making. This delegation refers to the rights of political agency that each individual possesses and may choose to exercise or delegate to others for implementation, either voluntarily or not (O'Donnell, 2010). All of this is based on the rule of law, which contemplates the establishment of laws and lower-level norms, as the basis of government and regulation of social coexistence.

The existence of leaderships in coastal areas is evidence of the power of delegation. However, to improve the capacity of individuals and coastal communities to achieve goals for these populations, these leaders must possess skills that enable them to manage the institutional-administrative frameworks and the resources to influence public management processes regarding their social issues.

In this regard, Sen (1992, 1998) refers to human capacity as the freedom of decision for the achievement of desired purposes based on individual and collective needs. Therefore, strengthening the capacity of coastal leadership should allow for the recognition of social issues related to vulnerability, so that these problems can be incorporated into public policy agendas. Thus, for a social issue to be addressed or tackled through policy, it must first be recognized as a public problem (Subirats *et al*., 2008).

Coastal social vulnerability in Costa Rica

In the study on coastal social vulnerability by Hernández (2023), it was technically defined as a multi-criteria variable of five sub-variables that characterize the population in its most critical elements and have a direct impact on the satisfaction of their human rights. For the case study, these sub-variables also needed to have available data for all coastal districts of Costa Rica, as the minimum geospatial unit that allows characterizing the coastline at the national level.

The sub-variables selected were "population" (projection to 2020 by the National Institute of Statistics and Census, INEC), "poverty" (percentage of the population with critical shortages, according to INEC for 2011), "local organization" (number of formal local organizations as of 2020, based on the definition provided by the Community Development

Law of the National Directorate of Community Development, DINADECO),, "health" (index of access to health services for the year 2017, data compiled by the Ministry of Planning and Economic Policy, MIDEPLAN), "education" (index of access to education for the year 2017, data compiled by MIDEPLAN) and "water" (index of inequality of access to the year 2013, data compiled by the Institute of Aqueducts and Sewerage (AyA).

The data for each variable were classified into five categories corresponding to the labels: "very low," "low," "medium," "high," and "very high" vulnerability, based on expert criteria in each case. The study assumed that social vulnerability is represented differently in each dataset according to the selected variables. Table 4.1 shows the criteria for each variable.

Table 4.1. Criteria to determine the degree of vulnerability according to variable and available data by district, Costa Rica.

Variable	Source of data	Criteria	Degree of Vulnerability
Population	INEC	Lower population per district	Very high
Poverty	INEC	Higher rate	Very high
Local organization	DINADECO	Fewer formal organizations	Very high
Health	MIDEPLAN	Lower rate	Very high
Education	MIDEPLAN	Lower rate	Very high
Water	AyA	Lower rate	Very high

Source: Hernandez, 2023.

After classifying vulnerability according to each variable, a weighted summation of the values by district was carried out to reclassify them again into 5 groups of data using the equivalent interval criterion. Finally, the "very low", "low", "medium", "high" and "very high" vulnerability conditions were determined (Figures 4.1 and 4.2).

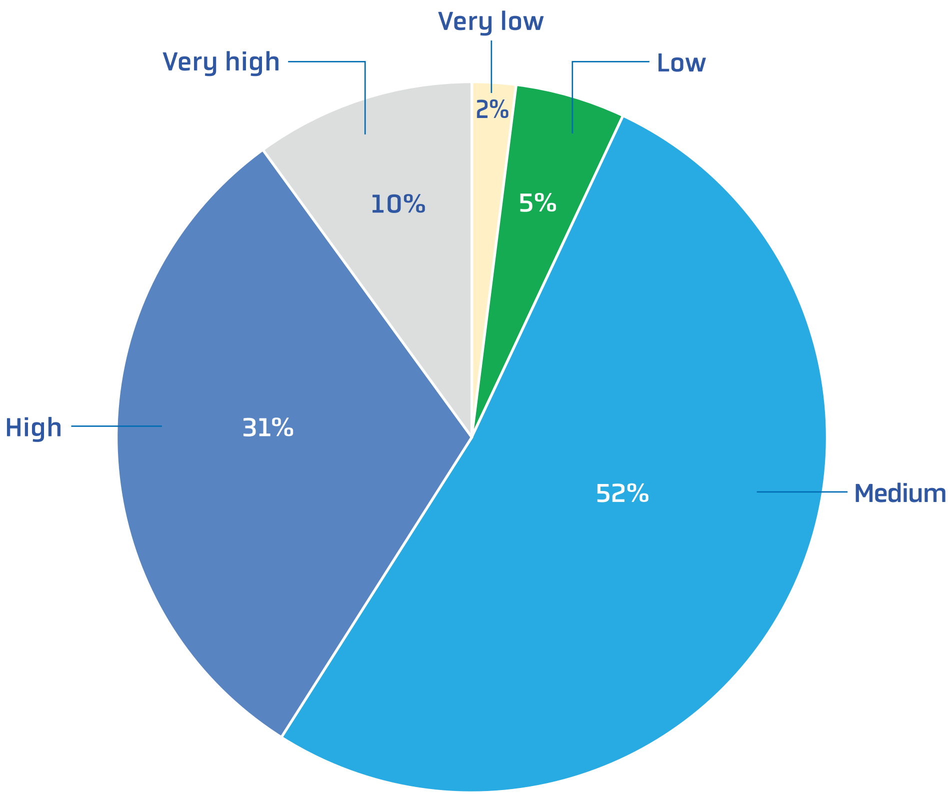

Figure 4.1. Percentage distribution of vulnerability ranking of coastal districts, Costa Rica.

Source: Hernández, 2023.

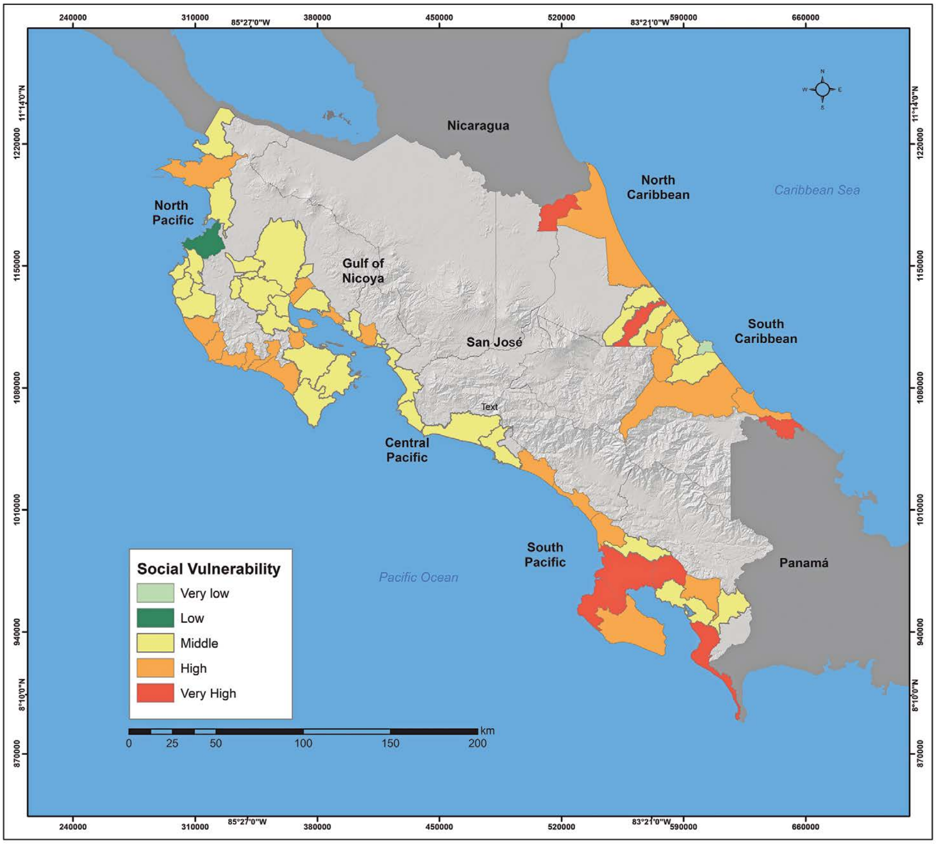

Figure 4.2. Geographic distribution map of Costa Rican coastal districts, according to their vulnerability classification.

Source: Hernández, 2023.

The results obtained from the multicriteria analysis (Hernández, 2023) confirmed the conditions of social vulnerability in the coastal districts of Costa Rica. One district was identified with "very low" vulnerability and two with a "low" level of the analyzed variable. The remaining districts showed "high" to "very high" categories, which correspond to the districts located in the southeastern Pacific and Caribbean (north and south) subregions. These findings align with the lowest scores in the latest version of the *Social Development Index* prepared by MIDEPLAN (2023).

Institutionality of coastal social management

On the other hand, and as a complement, an analysis was conducted of the constituent, functional, and operational aspects of the public organizations responsible for addressing coastal social development in Costa Rica. Additionally, the existing regulations related to Costa Rica's coastal public policy were identified. To achieve this, 24 formal national policy and planning instruments were reviewed (Hernández *et al*., 2021), of which 17 presented objectives, guidelines, strategies, or goals associated with marine and coastal aspects.

Within these instruments, 160 goals were identified that outline actions to address marine and coastal issues. These actions most frequently relate to fisheries, spatial planning and management, and environmental aspects, which together account for 93.7% of the actions (Hernández *et al.,* 2021). Meanwhile, actions specifically addressing social aspects were significantly lower, representing only 6.3% (Hernández *et al.,* 2021). This reveals a considerable imbalance in how public organizations manage social issues affecting coastal populations. In the implementation of the 160 goals or guidelines mentioned above, 56 organizations were identified as responsible for public administration in relation to marine and coastal issues. Of these, two bodies are the most important for their responsibility: the Costa Rican Institute of Fisheries and Aquaculture, which administers, regulates, and promotes the development of the fisheries and aquaculture sector, and the National Commission of the Sea, which is responsible for the implementation of the National Maritime Policy through an Ocean Governance Committee, characterized by discontinuous operation since its establishment in 2013.

Regarding organizations specifically responsible for addressing social actions within the marine-coastal sector, five out of the 56 organizations (just 8.9 %) were identified. On the other hand, 11 organizations (19.6 %) were identified as being of utmost importance in the government's agenda for actions in the country's marine and coastal sector, this is due to the frequency of assignments that are recorded in national planning and policy instruments. Coastal planning and land-use management fall under the jurisdiction of three state agencies (5.3%), in addition to coastal municipalities.

Final considerations

The large number of public agencies and regulations related to coastal areas and populations in Costa Rica has not achieved a correct articulation of actions aimed at comprehensive attention to their needs, which are reflected in the conditions of social vulnerability described in this document.

In addition to the above, it should be added that, currently, this institutional framework is not adapted to the country's coastal reality, particularly regarding two external factors that increase vulnerability: the first is related to climate variability and change, which intensifies environmental events in these populations' surroundings. The second refers to the rise in crime in coastal areas due to drug trafficking and the accumulation of informal debts, where struggles over territoriality and defaults on drug and debt payments have led to a significant increase in the number of homicides. Undoubtedly, these two factors will have to be considered for future updates of the state of coastal social vulnerability in the country.

Returning to the aspect of citizen political participation, it should be noted that an effective exercise of decentralization and redistribution of public administration at the regional or local level could have an impact on the management capacity of leaders of integral development associations and municipal corporations in coastal zones, both of which are close to the reality and social problems, in order to have more inputs to facilitate coordination of the state apparatus. This would make it possible to improve the current, insufficient possibilities for managing coastal social issues, which is evident in the gap between the large number of public policy instruments on fisheries and the lack of those focused on social issues.

Leadership in coastal zones is limited by a partial knowledge of the regulatory and administrative frameworks of public management, which is exacerbated by the multiplicity and overlap of the competencies and functions of the main public organizations related to coastal populations. This shows that the existing gaps in the capacity of state agency must be filled so that the tools of public management in coastal zones can promote the improvement of local capacities and thus the opportunities to manage the problems of the populations settled there and immersed in conditions of high social vulnerability.

Public policy to address social problems represents a way to address the vulnerabilities coastal zone inhabitants face; however, if there is a lack of knowledge of current national regulations, the limitations to recognize, manage, and demand the reorganization and execution of the competencies of public organizations will continue to increase. Therefore, it is highly relevant that these public agencies improve their management and enable programs and projects for the training of local coastal leaders in the functions of each agency. Academia can undoubtedly facilitate these learning spaces, as ICP has proposed as part of its support for the local coastal grassroots organizations with which it works.

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PART II
Identity and oceans

Women and fishing: a local appraisal of identity, subsistence, and climate change

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Historically, the oceans have been essential spaces in the evolution of the planet and human societies. At present, there is a renewed appreciation of the functions of the oceans, particularly in legislation that promotes their ecological conservation. These laws are based on national and international regulations, considering the threats posed by the Anthropocene and climate change. Discussions on this topic encourage the development of public policies and highlight some relevant but often overlooked aspects; an example is the relationship that certain coastal or riverside communities establish with the oceans, particularly the role of women, who are essential to identity and subsistence. Historically, women have contributed significantly and have been key actors in society's relationship with the oceans, although patriarchal structures have rendered them invisible. This marginalization is linked to their role in food security and poverty eradication, particularly in developing countries.

Addressing this gap, this chapter focuses on analyzing the relationship between fisherwomen and the ocean from a qualitative approach, using two case studies: Barra del Colorado, Costa Rica and Ilhabela, Sao Paulo, Brazil. In each case, an in-depth interview was conducted with wo men leaders and fishers (Table 5.1). First, a process of engagement was carried out with the interviewees to foster empathy and transparency in the consultations. Cases were selected based on knowledge from previous research, as well as on the status of these women as leaders in their local dynamic. The results analyze aspects such as the life stories of these women, their working conditions, and threats they face due to climate change. The study concludes that, from a political and economic perspective, women have been rendered invisible despite being guardians of ancestral knowledge which is currently under threat and must be considered in discussions on ocean management.

Table 5.1. Basic information of the interviewed women

Name of interviewee	Age	Location	Date
Neyba Martínez Forbes	65	Barra del Colorado, Costa Rica	September 21, 2024
Perla Wilson Allen	80	Barra del Colorado, Costa Rica.	September 22, 2024
Laurinda Maria de Moraes Lucio	65	Ilhabela, Sao Paulo, Brasil	November 09, 2021

Source: Own elaboration.

Artisanal fishing: social relevance

Fishing, along with hunting and, later, agriculture and livestock farming, have been strategic activities in the evolution of human societies. The relevance of artisanal fishing remains significant today and it is characterized by being a small-scale activity carried out on the shores of the oceans, riverbanks, and the margins of marshes and estuaries. In recent decades, this type of fishing has been affected by water pollution, obstacles imposed by coastal landowners, intensive fishing, and coastal tourism development, among other factors (Figueroa, 2021). In the case of Costa Rica, according to the Fisheries and Aquaculture Law, artisanal fishing is defined as fishing conducted without a vessel in rivers, lakes, or coastal zones, or fishing carried out aboard a vessel operating within a maximum of three nautical miles from Costa Rica's territorial sea (Law 8436/1, March 2005).In Brazil, there are no recent official fishing statistics quantifying the workers involved in family artisanal fishing; however, studies indicate that 70% of the country's food supply comes from these practices. Despite the difficulties, "the sea is a space of autonomy and resistance, a raw material for the creation of rustic utopias that mark the identity of fishermen and fisherwomen" (Ribaric, 2020, p. 46).

As stated by FAO and CoopeSoliDar (2022), fishing is not limited to being a source of income but is a way of life, shaped by traditions and knowledge that sustain families by providing food and education. Women participate in fishing to help support their households financially. In these communities, economic necessity drives women to take part in fishing activities. The role of women in fishing practices has gained increasing attention in research over the past decades and should be analyzed from their own lived experiences and symbolic perspectives (Gustavsson, 2020).

Although living conditions for fisherwomen are difficult, their capacities for work, organization and resilience should be recognized. These skills enable them to face risks and vulnerabilities, both from socio-economic and environmental perspectives (such as climate change). This is highlighted in the *Comprehensive Strategy for the Recognition and Formalization of Women's Productive Activities in the Main Value Chains of Small-Scale Artisanal Fishing, Recovering Traditional Knowledge and Practices*, developed by CoopeSoliDar R.L. (2019). This strategy is the result of a consultation process with a group of Costa Rican fisherwomen. In Brazil, community initiatives have been organized in protected areas along the entire Brazilian coast through CONFREM (National Commission for the Strengthening of Extractive Reserves and Marine Extractive Peoples). In this movement for artisanal fishing rights, the sea is not a territory without people, but "a dense anthropological place, collectively appropriated by artisanal fishermen through individual, collective and community forms of access and tenure that guarantee collective forms of survival, coexistence, and becoming" (Ribaric *op. cit.*, p. 46). The concept "maretorio", formulated by the fisherwomen, refers to the aquatic territory; thus, the sea, not only as a material foundation for traditional social life, but it is also where symbolic markers are imprinted, preserving the group's collective memory. This conceptual tie sustains a system of meanings from which existence is learned and experienced. Current political systems, at national and local levels, have rendered invisible the traditional knowledge and practices transmitted by women over generations. This knowledge, fundamental for climate change adaptation and mitigation, is at risk due to the dynamics of global capitalism. Resulting from their ancestral knowledge, they establish a spiritual relationship with the sea, which in some cases is unknown and is not considered within public policy discussions on the ocean.

The livelihood of fisherwomen and current threats

All the fisherwomen interviewed for this research, all elderly women, clearly exhibit conditions of poverty or extreme poverty, often supporting extended families; in the case of Costa Rica, the most critical situations are concentrated along the coasts (UNDP, 2023). In Brazil, fishing activity originated several regional coastal cultures; among them, the *jangadeiros*, *caiçaras*, *azorianos,* and *praieiros* (Diegues, 2004). However, the livelihood of artisanal fishermen and fisherwomen is threatened by the arrival of companies in their territories without an equitable process of consultation and dialogue with these communities (Begossi, 1998). The concepts of "structural time" and "ecological time" reveal social identities tied to land and sea, redefined by women (Fadigas, 2009). Recent feminist studies on Brazilian fisheries reveal the crucial role of fisherwomen in the cultural and economic impacts of fishing. The very definition of *artisanal fisherwoman* that is adopted appears in the discussions raised by Diegues (1999), who explores identity and theoretical-methodological issues shaping marine anthropology. Despite being largely invisible to the state, academia, and society at large, women play a crucial role in artisanal fishing. D. Laurinda Maria de Morais, a fisherwoman and artisan like many in her community, shares her experience:

> *My name is Laurinda Maria de Moraes, 59 years old, I was born on the beach of Castelhanos, in this beautiful place. I was born here in Castelhanos and grew up in the city, in São Sebastião. After a failed marriage, I remarried here in Castelhanos, I was born here and today being a woman in this place, being a woman in this community is very important, we have a simple but very pleasant life. I like the sea, I am a fisherwoman first and foremost and at heart I am an artisan, I love what I do, I like this place very much.... Our children are already the fifth generation, and I feel honored to live here to this day. I miss the*

good old days, where in the past it was really an isolated traditional community. Today, due to uncontrolled tourism, we are losing our freedom, but otherwise, we love this place.

Other research conducted in the Castelhanos community have shown that there is no sexual division of labor in the community; social roles are not defined by gender (França and Oliveira, 2022). This contrasts with the situation in Costa Rica. Doña Perla, one of the interviewees from Barra del Colorado, raised eleven children, as well as eleven others: among grandchildren and informally adopted children, which confirms the predominance of single women or women separated from their husbands as heads of households and forming extended families within the fishing practice. Thus, women who are partially or totally dedicated to fishing activities are more vulnerable. According to Peralta (2022), this is due to the demographic burden of households, disadvantageous conditions of entry into the labor market, inequity in labor relations and lack of opportunities derived from gender stereotypes.

These women safeguard traditional knowledge on the relationship with the oceans, understood as knowledge of the natural and supernatural world, transmitted orally from generation to generation. Doña Laurinda from Ilhabela, Sao Paolo, Brazil, proudly claims to be the fourth generation of a lineage where her sons and daughters represent the fifth generation continuing such knowledge. Such ancestral management has sometimes been recognized as a historical right of traditional peoples (Indigenous, Afro-descendants, Caiçaras,[16] among others) to their territories, including access to the sea. However, this ancestral knowledge is sometimes threatened by new forms of coastal and ocean governance. Doña Neyba, in her interview regarding the establishment of the Barra del Colorado Wildlife Refuge, expresses her frustration:

16 A category of traditional people resulting from the interculturalism of indigenous, Portuguese and enslaved Africans from the coasts of São Paulo and Paraná, Brazil.

We have always fought with MINAE (Ministry of Environment and Energy). Our grandparents, our ancestors, took care of this place, and now they come and say they are the ones protecting it. Since when? If we had not taken care of the woods, nothing would be left. There would be no wetlands or vegetation because we took care of them, but when the refuge was established here, it caused us great harm. Now we cannot cut even the smallest leaf in the forest. All our customs changed for the worse...”

Figure 5.1. Doña Perla (left) and Doña Neyba (right). Barra del Colorado, Costa Rica. Source: @Carlos Morera. September 21, 2024.

The new models of coastal occupation and the environmental conditions of the seas threaten the livelihoods of the people who inhabit them. Thus, the development of tourism projects, intensive fishing, the establishment of protected areas and the expansion of monoculture crops are factors that disrupt the way of life of these communities. As such, women are the most affected, because they have the strongest roots and identity with coastal territories. This is testified by the three women who were interviewed, whom, despite the challenges, have not migrated elsewhere. As evidence of the above, Doña Laurinda states that "... *they are part of a community suffocated by external pressures, but they resist through time*". These women are evidence of a culture of resistance against the hardships imposed by capitalism. Their leadership stands out; for instance, Doña Neyba participates in more than six organizations (defense of the health system, women, Afro-descendants, women entrepreneurs, among others). Thus, a positive aspect that has been identified is that women, in relation to men, have a greater capacity to organize themselves and even lead such processes. Unlike men, women have shown a remarkable capacity for agency and resilience in the face of socioeconomic adversities, as shown by Doña Neyba in her participation in multiple organizations. All this reflects a strategy of resistance and empowerment in the face of dominant structures. Thus, these women become agents of change by leading initiatives that seek to transform their communities.

Fishing is a shared and asymmetrical job

Fishing is a shared occupation between men and women that combines actions for both the market and subsistence. The dynamics of today's capitalist society disrupted ancestral capacities of traditional communities, which they replaced with subsistence. A market system based on supply and demand was imposed, with gender-differentiated functions. While men have greater responsibility in market actions, women are more focused on subsistence. Thus, according to the interview with Doña Neyba, she carries out fishing activities on a permanent basis for survival. And, occasionally, when the Barra del Colorado Fishermen's Association requires specific tasks, such as preparing shrimp (heading and peeling), it is done by the Women organized as the Barra del Colorado Shrimp Peelers and Processors Association.

All the interviews identified that fishing for women is a subsistence activity supporting household nutrition, which can temporarily become a source of income and be highly valued due to economic shortfalls facing these coastal communities. Even though it has a relevant function in the subsistence of these families, the value of fishing and associated activities such as shellfish harvesting, mollusk collection, among others, is not properly recognized, despite being crucial for family survival. Thus, women like Doña Neyba affirm that "*with the little I have, I go fishing and I have food for the day*". Similarly, Doña Perla replies, "*... I would go fishing by boat with my children and bring back my food, enjoy the time with my children, and forget all my worries*".

Furthermore, the connection extends beyond fishing, encompassing spiritual, philosophical, and creative aspects. Doña Laurinda, drawing from her lifelong experience with the sea, was inspired to create a line of handicrafts that provides additional income (Figure 5.2). In addition, the two women interviewed in Barra del Colorado explained that their adverse living conditions have led to depression and sadness, which were eased when they spent time at sea. The spiritual connection with the ocean is evident in their personal reflections, such as Doña Perla's statement: "*without the sea I would die... Once I went to San José and I had to return*". For her part, Doña Laurinda mentions:

> *"For me, living here is indescribable. First, because of the view I have. When I open the window of my bedroom early in the morning, the sea is in front of me; fresh air, a wonderful view that no one else but I have. I am very happy, I thank God every day for the place where I live, the place where my father (God) gave birth to me, a little bit of creation...".*

Figure 5.2. Dona Laurinda, Sao Paulo (2019).

Source: @SueliCFurlan. October 17, 2019.

Women fishers and climate change

Women fishers employ traditional fishing methods, such as the use of pole and line; in most cases, they do so in small boats. However, the lack of access to modern technologies and restrictions imposed by the Barra del Colorado Wildlife Refuge Management Plan (Sinac, 2017) prohibiting the use of gillnets and cast nets, limits their options, and reduces their productivity.

New forms of fishing displace traditional forms which have a smaller ecological footprint. This substitution implies the use of more invasive methods that deteriorate fishing productivity conditions, as stated by the two women interviewed in the Barra del Colorado community. They mentioned that the amount of fish is gradually decreasing. This is the most relevant change identified by the women interviewed in relation to climate change. However, they acknowledge that, historically, they have observed sea levels rising and falling, which is why their houses are built on stilts. They also recognize that nature is dynamic and constantly changing. Doña Neyba affirms that *"the river changes its course every year and we must understand this, so we are not caught off guard"*. The two women recognize stronger hurricane and storm conditions, although they do not dare to state that it is due to climate change, because this concept is not something they master on a scientific basis. Both women are deeply concerned about the growing problem of marine plastic pollution. They point out that this situation is aggravated by an unsustainable consumption model that prioritizes production and disposal of plastic products, making alternative solutions and their environmental impacts less visible

Concluding remarks

Ocean management implies multidisciplinary and multisectoral approaches that incorporate all social groups, including traditional communities such as Afro-descendants, indigenous or peasant communities, which have established a relationship with the oceans that is not limited to obtaining resources, but also incorporates spiritual and subsistence aspects. The cases addressed in this study show that these social groups are repositories of ancestral knowledge that is threatened by the new dynamics of coastal spaces and are valuable as lessons learned in the definition of urgent actions for adaptation to climate change. Seas and oceans are spaces with people who have historically established a relationship of spiritual, economic, and cultural identity that is currently threatened.

These results highlight the need to design specific interventions for fisherwomen and to recognize their fundamental role in the struggle against poverty and towards marine conservation. The development of public policies that value their traditional knowledge and promote sustainable practices is crucial, as previous experiences in some nations have proven to be effective in adapting to climate change, especially from a sociocultural perspective.

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Poeticizing the ocean: an artistic experience at the DSL

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A man in a full suit and tie, extremely worried and tense, enters the stage, as he asks the person with whom he is talking for more time to deliver his work. His blood pressure goes up, he tries to loosen his tie, his breathing shortens, he feels a pain in his chest. One can hear his heart pounding, from percussion sounds. A woman appears, approaches him with a virtual reality goggle, and puts it on, the man is submerged in the sea and gradually calms down. The man, being submerged in the

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ocean, observes the various marine species; fish, turtles, sharks, jellyfish, dolphins, as well as excerpts of poems inspired by the immensity of the sea. The man is calm, the woman approaches him. He takes off his virtual reality goggle, and the woman embraces him.

Description of the inaugural scene at the CISOS24

Is it possible to imagine a future where the only way to experience the ocean will be through virtual reality? This question is one of the starting points of the artistic intervention *Dimensions of the Ocean*, presented at the Congress on the Integration of Knowledge for a Sustainable Ocean (CISOS24). The artwork invites us to critically, reflectively, and artistically question our relationship with the environment, reality and, specifically, the ocean.

The Dimensions of the Ocean project, which is an artistic investigation carried out in the Laboratorio Escénico Digital (LED) de la Escuela de Arte Escénico de la UNA (UNA, Costa Rica), employs a series of creative and technical processes that highlight what inspires, moves, frightens, and unsettles us about the ocean. This project is developed collaboratively by academics and students. This chapter explores three of the processes that comprise the various phases of this artistic process involving implementation of interdisciplinarity and intermediality to raise awareness -through an artistic lens- about the importance of protecting the oceans.

The first process of creation and research focuses on the 3D printing of selected marine species. The second one concentrates on the generation of 3D images and the last one links the previous works in the production of the scenic device, the technical staging, and the criteria to maintain a relationship between the technical and poetic elements.

Artistic work of this nature not only deepens the techniques used in each component (video, 3D printing, the creation of the scenic device), but also fosters an interdisciplinary and intermedial dialogue. The intersections of these diverse creative processes propose playful ways of addressing the challenges facing the oceans, offering a different kind of experience to raise awareness about their sustainable management.

3D printing: marine species and digital technology in the creative process

Currently, ocean pollution and threats to marine species are urgent issues in various research and governmental areas, as they significantly impact the biodiversity of the planet. Within this framework, digital tools such as modeling and production through 3D printing emerge as multidimensional means for the creation of practical design solutions to represent these marine species. Furthermore, these tools address the issues of oceans and marine life in an educational, didactic, artistic, and awareness-raising manner regarding today's environmental challenges. Campi mentions: "No one knows with too much certainty how to formulate the new alliance between technology and culture that the era of information and global warming require, but let's hope that the designers of the future know how to unravel this mess..." (2020, p.109).

Most of the materials used in the manufacture of products through 3D printing are derived from petroleum, posing a threat to marine life. This situation generates a paradox: 3D printing as a creative means to represent the life that inhabits the oceans. This dilemma between technology and environmental impact invites reflection on the responsible use of these materials and sustainability, particularly concerning the seas and marine life.

Given this premise, the various existing 3D manufacturing materials are analyzed, and PLA (polylactic acid) materials are used as an alternative. This material was selected for its suitable processing properties that are different from the various existing 3D manufacturing materials. According to Gómez, "PLA is a thermoplastic of natural origin obtained from the fermentation of starch, cassava, or sugar cane, and is characterized by being highly biodegradable" (2020, p. 285). Therefore, in a metaphorical way, PLA can be considered as an extension of plastics, which increases the current problem of the oceans. This association enhances the relevance of current debates on the accumulation of microplastics affecting ocean ecosystems.

Regarding the conceptualization and 3D fabrication process, the approach focused on studying and observing scientific illustrations: describing the shapes, textures, and morphological structures of species through modeling and 3D printing. The exploration phases of the technical-digital software made it possible to develop three-dimensional designs and models into effective visual teaching tools for a reflexive analysis of species and the environment. For Campos, 3D modeling "…thus becomes a highly effective and versatile representation system, because it inherits the functional advantages of vector scaling..., the hyperrealism of raster drawing..., and also introduces the three-dimensional visualization of the object from any angle..." (Cited by Cabezas and Lopez, 2016, p. 266). Therefore, 3D digital tools allow an approximate representation of marine species in a visual, dynamic, tangible, and accessible way for all types of audiences with these currently endangered creatures.

For the modeling and digital sculpting of the marine species, the open source program Blender (https://www.blender.org) was used, which integrates a range of possibilities including modeling, sculpting, and even creating dynamism to digital proposals in 3D. This allowed rapid production of the design and its ideal export in STL formats for its three-dimensional printing process.

With the support of specialists, seven threatened marine species were selected: leatherback turtle *(Dermochelys coriacea*), thresher shark (*Alopias pelagicus*), sailfish (*Istiophorus platypterus*), moorish idol *(Zanclus cornutus*), manatee (*Trichechus manatus*), giant parrotfish (*Scarus perrico*) and the hammerhead shark (*Sphyrna lewini*), which inhabit Costa Rican marine ecosystems. In this first phase, collection of information provided by specialists was crucial to establish guidelines and understand the design proposal. Next, the study and visual organization phase for each species helped define future development lines and advance the creation of three-dimensional models using the appropriate software. This work was carried out in the Laboratorio 3D de la Escuela de Arte y Comunicación

Visual at Universidad Nacional, incorporating key elements such as visual representativeness, shape, texture, and dimension, among others.

Subsequently, the models of the species were verified using the 3D printing profiling software. During development, certain parameters were adjusted, and the filament (material) was chosen for final production using the 3D printer (Figure 6.1). This digital design process "[...] must have a method that allows you to complete your project, with the right material, the precise techniques, and the form corresponding to its function" (Vilchis, 2014, p. 44). Therefore, methodological phases were established to ensure a smooth production process, emphasizing collaboration and the exchange of knowledge in a critical, reflective, and didactic manner among design, art, and science disciplines.

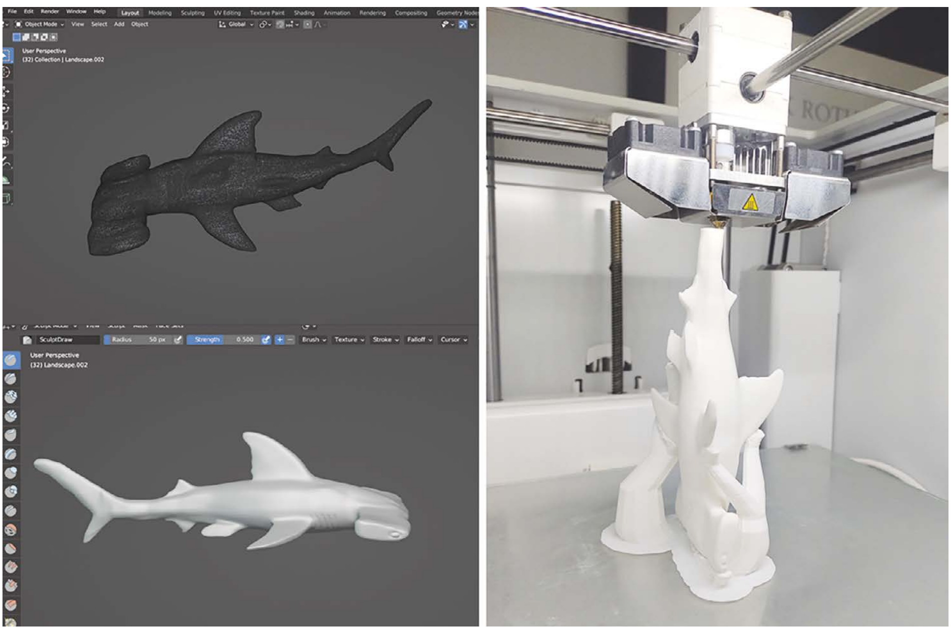

Figure 6.1. Conceptualization and manufacturing: development of models in the three-dimensional software, followed by the next phase of manufacturing using a 3D printer.

Source: Own elaboration.

Technological innovation through 3D modeling and printing provides a visually appealing, effective, and creative means of communication, however, it is also essential to consider the approach and issues from a reflective, educational, and critical perspective regarding the preservation and protection of the oceans and marine life. The metaphor as a powerful tool, invites reflecting upon the association between marine life and human activity through visual discourse and 3D printed material.

The three-dimensional representation of marine species using this technique makes them appear both fragile and attractive, however, the filament used as a material serves as a reminder of plastic's role in other types of 3D materials and the pollution it can cause when not used appropriately and responsibly.

3D Modeling and Animation: Ocean Dimensions

Another key component used within the framework of the Dimensions of the Ocean project is 3D modeling. This component was used for scientific dissemination and environmental awareness. Initially, three-dimensional models of marine fauna were created and then animated, allowing the public to be submerged in a virtual underwater environment, generating an immersive and educational experience. Specialized 3D modeling software, such as Cinema 4D, was used to create detailed digital representations of various marine species. Starting from basic models, digital sculpting, texturing, and rigging techniques were applied to achieve realistic appearances and smooth movements. These models were later integrated into a virtual environment and projected through videomapping, creating an immersive experience for viewers. One of the fundamental aspects of this proposal is the digital recreation of marine animals through 3D modeling.

The modeling process involved research on the anatomy of marine species and the use of specialized digital tools. This was carried out using primitive shapes (Figure 6.2, image 1), which were then refined by applying modifiers and textures to achieve a realistic representation. The Maxon suite, which includes *Cinema 4D*, was used as it is a professional software solution for 3D modeling, animation, simulation, and rendering. The research, based on experimentation, began with the modeling of a jellyfish (figure 6.2, image 2.), starting from primitive shapes. In this case, a spline (a section built by a nerve) was used, along with modifiers and other software tools, to achieve a more descriptive state of the 3D object (figure 6.2, image 3).

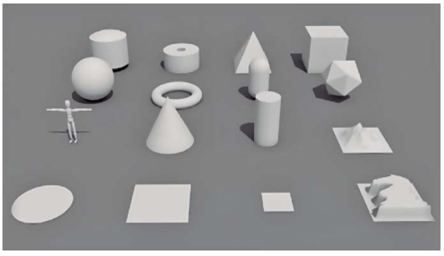

Image 1. (Screenshot)

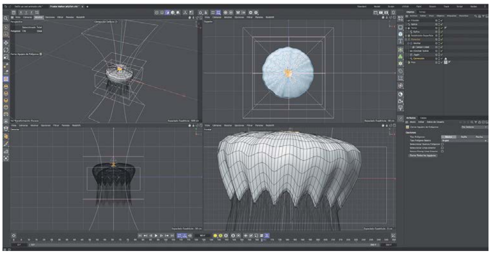

Image 2. (Screenshot)

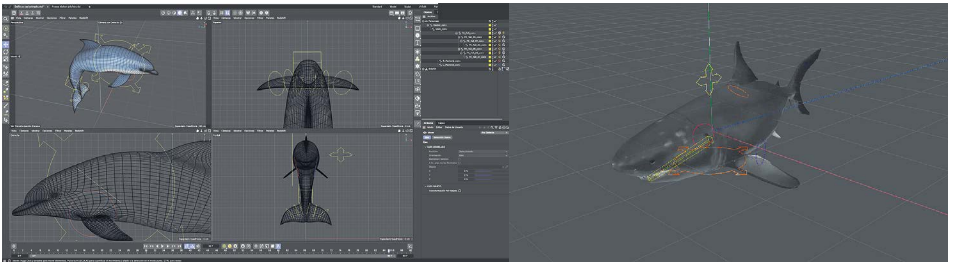

Image 3. Rigging (union of the skeleton as simulated by the software, with the geometry of the 3D object)

Figure 6.2. Presentation of the stages in the process of conceptualization and digital construction of 3D objects.

Source: Own elaboration.

In the process of digital design and 3D modeling, it is essential to understand certain terms directly related to animation and video production: (a) rendering is the final process of generating an image or video and refers to the computer's processing of interpreting and producing a final image or frame-by-frame sequence of a video or animation; (b) rigging is the process of digitally animating a 3D object by employing a digital skeleton to match it with the object's polygons; (c) video mapping uses various technologies such as high-end projectors, motion sensors, a properly preselected and measured space, video and lighting.

Several tests were conducted following the creation of the first "jellyfish" model, to efficiently address the challenge of modeling marine animals in 3D. However, organic modeling required a level of detail that exceeded the time available for the project, so it was decided to complement with pre-existing high-quality models available from digital resource banks.

For the 3D shark model, several open license websites were identified. After creating the 3D models, they were animated using the rigging technique to simulate the animal's natural movements. The animated models were then rendered to generate high-quality images that were projected onto LED screens and irregular surfaces using the videomapping technique. As part of this process, four animation videos were produced: two of dolphins swimming (one frontal and one top-down view) and two of a shark (also frontal and top-down views). From the initial models (dolphin and shark), multiple copies were created in the same file, to simulate several animals swimming together. This approach enhanced realism, and the background was left transparent (Figure 6.3) to allow for the animations to be placed on different backgrounds.

This project generated an immersive experience that transported the viewer to the bottom of the sea. An emotional connection with the digital proposal of the marine world was generated, making the public aware of the importance of its conservation. Feedback is required for each stage of the process, as project guidelines must always be present in the development of visual inputs. Each 3D object requires considerable time for its construction, from the initial file to the level of finishing and animation. For a better use of human resources, it is advisable to work on the models simultaneously. This can be done through video or static form, although this requires professionals for each 3D modeling.

The development of 3D animals and their rendering for mounting on screens or videomapping entails a previous and thorough analysis of lighting, expected use, type of background, projection time, and size of each digital medium. To speed up and optimize modeling time using resources and online image banks; whether 3D or 2D and other resources (video, lights, and others), the recommendation will depend on the degree of complexity of the project and the time required for its development and assembly.

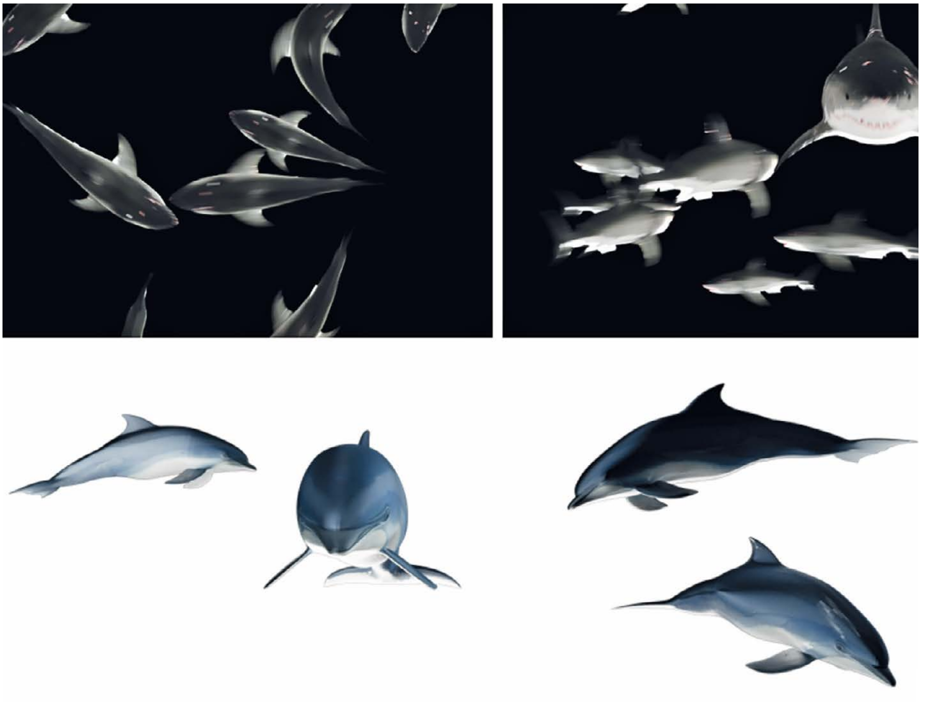

Figure 6.3. Animation process of 3D objects from different perspectives.

Source: Own elaboration.

Technology and techniques to create immersive, interactive, and poetic factors in the Dimensions of the Ocean proposal.

3D printing, as well as 3D modeling and animation, demonstrate how advanced technologies offer a more accurate understanding of marine ecosystems. These digital resources shape the scenic device, utilizing mapping as one of the first elements for projecting detailed images and videos of marine landscapes onto physical structures. This creates a simulation of underwater environments that "come to life." The second element is a LED floor, which was activated by the movement of people's bodies, and the third element is virtual reality, allowing the audience to experience a real immersion into the ocean by wearing virtual reality goggles.

The integration of these technologies required meticulous planning to ensure that each projection, artistic creation, and program was tailored to the unique characteristics required for each moment of CISOS 2024. The result was an almost total immersion into a simulated marine ecosystem.

This type of projection is capable of evoking a sense of splendor and mystery, allowing people to dive into coral reefs, interact with sea turtles, or explore the ocean floor. Ultimately, the experience leads to a sensory journey that enables participants to emotionally connect with the underwater habitat. The mapping technique was used in this case to create an immersive transformation of the space into marine landscapes. Mapping requires careful preparation and adjustments to ensure that each projection adheres to the unique qualities of the projected surface, and a dramatic interplay between scenes and videomapping. Achieving immersion through the recreation of a digital marine ecosystem transformed the physical space into a vibrant and enveloping oceanic environment. These projections create an experience that can inspire awe or provoke reflection in the audience as they observe a coral reef, a sea turtle, or humanity's interaction with the reflected ocean (Figure 6.4). Additionally, the experience becomes a sensory adventure, fostering an empathetic connection between participants and the aquatic world. This bond not only enhances the perception of the marine environment but also promotes greater sensitivity toward its sustainable management.

Another key element of the scenic device is the interactive LED floor, designed to encourage interactivity and offer a unique tactile experience. This technology combines LED displays with motion sensors, creating a surface that responds dynamically to activities performed on it. In the context of ocean research, the floor simulates the sea, allowing participants to explore this environment visually and tactually.

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Figure 6.4. *Video Mapping*, during Dimensions of the Ocean (CISOS 2024).
Source: @Paula Amador, 2023.

To take advantage of this technology, it is necessary to run integrated hardware and software on computers that are compatible with the floor system, in addition to configuring the corresponding commands. The sensors must accurately capture both the movement and location of people, ensuring that the images projected on the floor are updated in real time (Figure, 6.5). The design of the floor allows for physical interaction with a simulated marine environment, offering users the ability to walk on a surface that mimics the water or seabed. This interaction generates an immersive tactile and visual experience that deeply inspires and bonds with the aquatic environment.

Figure 6.5. The floor is a touch screen that is activated by people walking on it.

Source: @PaulaAmador, 2023.

Finally, virtual reality goggles allow total immersion in a simulated scenario in the underwater world; that is, by programming and generating a base that simulates a desired environment or space. People explored the ocean from a first-person perspective, meaning that the use of virtual reality headsets created a direct connection with the underwater world.

Virtual technology simulates the act of diving and exploring beneath the surface. As a result, virtual reality requires a considerable amount of graphic and processing power to achieve a convincing sense of immersion. Virtual environments involve the creation of full 3D models, textures that resemble the visual appearance of the ocean. Precise synchronization and real-time head tracking are critical to ensuring that the person experiences proper immersion. Likewise, the ability of VR systems to handle real-time interactions and responses is vital to producing the sensation.

Thanks to the incorporation of technologies such as immersive mapping, interactive LED flooring, LED screens and virtual reality goggles, the technical setup for ocean research has revolutionized the way marine ecosystems can be explored and understood. The implementation of both technical and poetic criteria offers a global and detailed image of the oceans in a dynamic way, generating an exceptional visual and emotional impact. By juxtaposing narrative with cutting-edge technology, the technological frameworks allow people to visualize the marine world in a meaningful and profound way, focusing their attention on its wonder and the need for its preservation.

Conclusion

This artistic research demonstrates how art and technology become fundamental tools for ocean awareness and literacy. The approach encourages care, preservation, and enjoyment of the valuable natural resources we have. The creative process evidences a relevant connection, which allows activating diverse languages and establishing sensitive relationships with other people. On this occasion, it is a matter of learning about marine ecosystems, their threats, and their importance, while asking crucial questions about the future.

Returning to the epigraph presented at the beginning of this text, the hope is that the answer to these questions is not solely virtual reality. However, this technology emerges as a powerful tool to reach people in a different way, thereby contributing to awareness of the importance of preserving the oceans.

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Part III
Monitoring and measurement

Co-creation of knowledge and tools for tsunami preparedness

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Tsunamis are surface gravity waves that can occur in any body of water and arise from a sudden disturbance of its surface happening rapidly over a sufficiently large area. Earthquakes are the most common source of tsunamis, but they can also be caused by submarine or subaerial landslides, volcanic eruptions, meteorites and atmospheric pressure changes. Tsunamis are rare, but they can have a huge impact; for example, nearly a quarter of a million people died in the Indian Ocean tsunami of December 2004.

In Costa Rica, a small country having coasts on two oceans: Pacific and Caribbean (Atlantic), there is a popular belief that tsunamis do not occur on national territory; however, at least 42 tsunamis have been identified, of which 36 were recorded on the Pacific coast, five on the Caribbean coast, and one occurred on both coasts (Chacón-Barrantes *et al.*, 2021).

Fortunately, the impact that these tsunamis have had on the country has been moderate (Figure 7.1), mainly because the nation's coasts were historically sparsely populated until the 1990s. However, although the potential for tsunamis in the country is not as large as in Chile, Japan or Indonesia, past tsunamis in Costa Rica would have a much greater impact today due to the rapid population growth in coastal areas in recent decades. This impact could be even greater should it occur during the high tourist season.

After the tsunami that struck Nicaragua in 1992—the largest ever recorded in Central America to date—efforts began in the region to work on tsunami prevention and preparedness. As part of these efforts, an inventory of tsunamis that had affected the country was initiated and some isolated initiatives were implemented to improve tsunami preparedness (Fernández-Arce & Alvarado-Delgado, 2005). However, until 2014, no organization was in charge of the tsunami threat as such, nor were there any systematized national prevention efforts, nor any efforts for attention to events in real time, known as "alerts". This is why SINAMOT (National Tsunami Monitoring System) was created that year to address tsunami alerts, at first as an academic activity linked to the RONMAC Program (Sea Level Monitoring and Coastal Hazards Research Network) at the Departamento de Física of the Universidad Nacional.

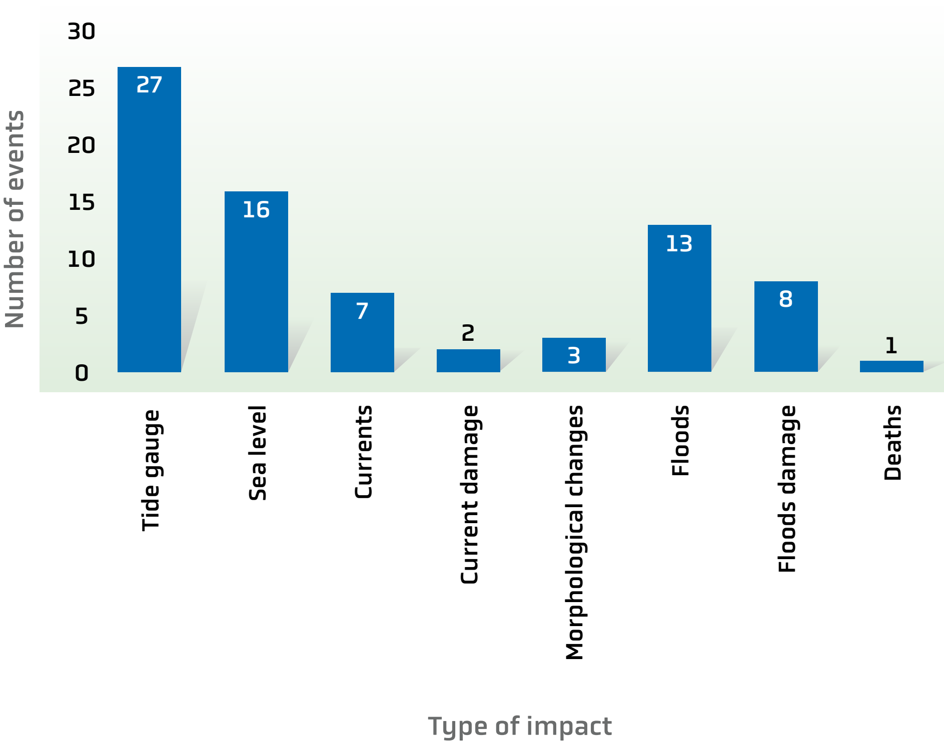

Figure 7.1. Observed effects of tsunamis in Costa Rica from 1746 to 2022: recorded in tide gauges, changes in sea level reported by witnesses, abnormal currents recorded by witnesses, damage caused by currents, morphological changes such as erosion or sedimentation, flooding, damage from flooding, and fatalities. The figure shows the total number of times each effect was observed. Many tsunamis had effects in multiple locations.

Source: Modified from Chacón-Barrantes *et al.*, 2021.

Later, following a reorganization, SINAMOT evolved into a dedicated tsunami program focused on four key areas: research, monitoring, alerts, and prevention. SINAMOT is now a consolidated interdisciplinary space with professionals in physics and geography, articulated with experts in other fields such as psychology, sociology and environmental sciences, enriching the Program and enhancing its results and scope. In addition, the

SINAMOT Program has played a very active role in the Intergovernmental Coordination Groups (ICG) of the Pacific Tsunami Warning Systems (ICG/PTWS) and the Caribbean and Adjacent Regions (ICG/CARIBE-EWS). These ICGs are subsidiary bodies of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

Characterization of Tsunami Threat and its Applications

In order to work on tsunami prevention, it is necessary to characterize the threat. For this reason, it was necessary to define tsunami flooding areas for both coasts of the country, as well as estimate minimum arrival times. For this purpose, SINAMOT conducted tsunami hazard studies for both coasts (Chacón-Barrantes & Arozarena, 2021; Chacón-Barrantes *et al.,* 2022), which were carried out within the framework of agreements for the development of tsunami evacuation maps with the National Commission for Risk Prevention and Emergency Attention (CNE). Threat studies considered only tsunamis generated by local, regional and distant earthquakes with homogeneous ruptures, through the aggregation of scenarios (Álvarez-Gómez *et al*., 2013). Definition of these earthquakes was based on historical events, pre-calculated sources, sources defined in the literature and in meetings of tsunami source experts organized by the IOC/UNESCO Tsunami Program (Chacón-Barrantes & Arozarena, 2021; Chacón-Barrantes *et al*., 2022). In the years to come, threat studies will be updated to include other tsunami sources, such as earthquakes with heterogeneous ruptures and non-seismic sources.

Costa Rica has 315 coastal communities, and it was necessary to define which ones required tsunami evacuation maps. In addition, there is no high resolution coastal bathymetric data available to model tsunami flooding along both coasts; these data only exist for a few locations. Although SINAMOT has the capacity to carry out bathymetric surveys, these are expensive, and it was necessary to establish priorities among communities.

For this, it was decided to propagate all tsunami scenarios considered to a depth of 20 m. Subsequently, maximum heights in front of each beach resulting from these propagations were extracted and maximum values were used to define a threat index (Figure 7.2). In parallel, a vulnerability index was defined, considering aspects such as population, tourist visitation, road network, and terrain slope (Rivera *et al.*, 2016), in order to define a tsunami risk index for each community located along either coast of the country. Currently, tsunami evacuation maps have been developed for a total of 67 coastal communities, 58 in the Pacific and 9 in the Caribbean. The CNE has placed 366 tsunami evacuation route signs in approximately 20 of these coastal communities.

In areas where coastal bathymetry was available or where bathymetric surveys were conducted, tsunami flooding was modeled numerically to delimit flooding areas and minimum arrival times. Flooding areas were defined by overlapping flooding areas caused by all considered scenarios. Thus, it was found that distant and regional tsunamis cause more widespread flooding than local tsunamis in the Pacific. In the Caribbean, the same is true for some locations, but in others, local tsunamis cause more flooding than regional tsunamis. On the other hand, arrival times of local tsunamis on both coasts can be as short as 2 minutes, depending on location (Figure 7.3).

In most locations, these reduced arrival times correspond to relatively small flooding areas, and not to the maximum flooding areas, caused by regional and distant tsunamis. Therefore, it was decided to define two tsunami flooding areas: a smaller and a larger one. Thus, people in these communities are advised to leave the smaller flooding area in the shortest possible time in the event of a strong earthquake. On the other hand, having two different flooding areas makes it possible to scale evacuation recommendations for regional and distant tsunamis, on a case-by-case basis.

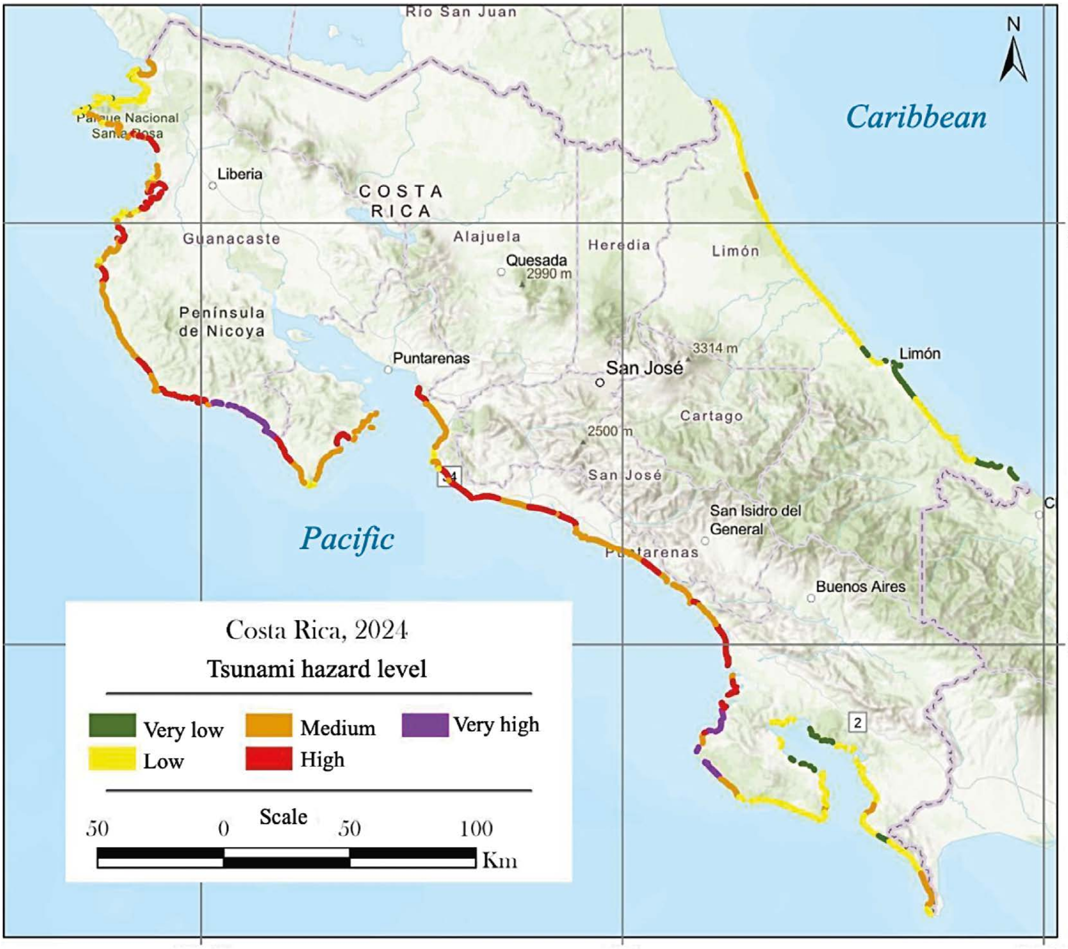

Figure 7.2. Tsunami threat index map.

Source: Modified from Chacón-Barrantes & Arozarena, 2021; Chacón-Barrantes *et al.*, 2022.

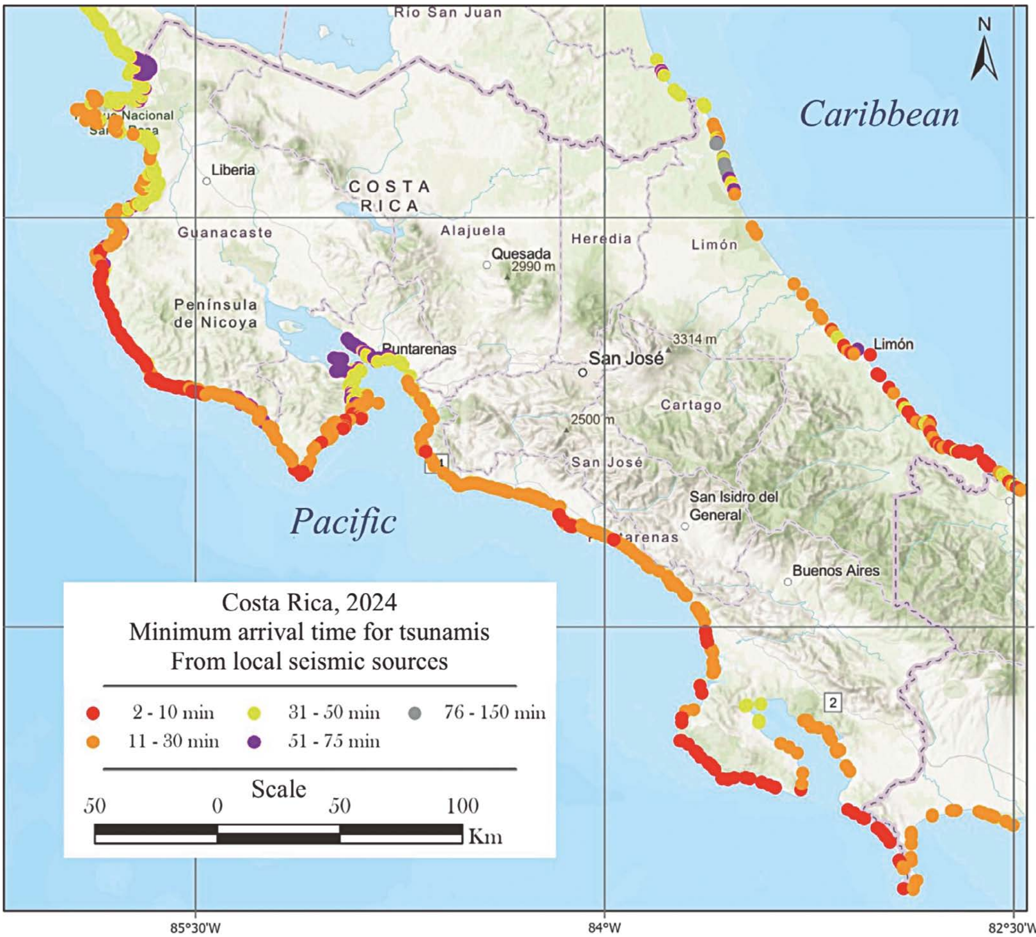

Figure 7.3. Map of minimum tsunami arrival times to Costa Rica in minutes.

Source: Modified by Chacón-Barrantes & Arozarena, 2021; Chacón-Barrantes *et al.*, 2022.

For areas where high-resolution coastal bathymetry is not available, maximum heights obtained in threat studies were scaled to define a maximum height at the coast. Then, flooding areas were defined as all zones whose height above sea level was lower than the maximum height at the coast. This was validated by testing this approximation in areas where tsunami flooding was numerically modeled, with effective results.

Next, it was necessary to prepare evacuation maps for the communities, which had to include tsunami flooding area(s), meeting points and tsunami evacuation routes. To define tsunami evacuation routes, a methodology was designed to validate the Geographic Information System (GIS) with participatory mapping. For the definition of tsunami evacuation routes through GIS network analysis, methodologies used in other countries (Scheer *et al*., 2011) were used to calculate the most efficient routes for people to reach meeting points, considering the number of people to evacuate, the capacity of the road network, and the meeting points. Subsequently, participatory mapping workshops were organized with the communities and their emergency committees, where they were first trained on tsunamis and then presented with evacuation areas for their communities. They were asked to define meeting points and evacuation routes before being shown the results obtained through network analysis. In most cases, the results obtained from both approaches coincided, and in cases where there was a discrepancy, it was discussed with the communities to reach a consensus, prioritizing local knowledge. This methodology is an excellent example of co-creation of knowledge which also allows the people in the communities to take ownership of tsunami evacuation maps and other prevention tools, ensuring a more active and sustained participation over time (Figure 7.4).

Twenty of the communities that were involved were so motivated when using this methodology that they wanted to go beyond tsunami evacuation maps and requested support to develop tsunami preparedness and response plans; they were even willing to work on the twelve requirements to be recognized as Tsunami Ready by IOC/UNESCO. This is a worldwide standardized recognition based on coastal communities' efforts to be better prepared for tsunamis (UNESCO/IOC, 2022). Costa Rica and Indonesia are worldwide leaders in this recognition. To date, 11 communities have been recognized in each country. In Costa Rica, 10 of these communities are on the Pacific and one on the Caribbean coasts.

Figure 7.4. Members of emergency committees in the city of Limón developing their tsunami evacuation map. Source: @SilviaChacón, 2023.

The progress achieved by SINAMOT in tsunami preparedness on a national scale in such a short period of time and the IOC/UNESCO Tsunami Ready recognitions have generated worldwide acknowledgement. This led to an invitation to be trainers at the "Regional Tsunami Evacuation Mapping Workshop" held in Barbados in 2022, organized by the IOC/UNESCO Tsunami Program and the United States Oceanic and Atmospheric Administration (NOAA) Tsunami Program. Thus, the methodology developed in Costa Rica was shared with other Caribbean countries, allowing some of these countries to develop or update their own tsunami evacuation maps, without depending on international cooperation projects.

In addition, the defined tsunami flooding areas are publicly available on SINAMOT's website (www.tsunami.una.ac.cr). In 2022, an agreement was signed with the Ministry of Housing and Human Settlements (MIVAH) to share these flooding areas through the GeoExplora platform managed by MIVAH. It is hoped that soon these flooding areas will also serve as a reference in the new version of the Seismic Code of Costa Rica, which will include a text on the tsunami threat. SINAMOT has agreements with the National Commission for Risk Prevention and Emergency Attention (CNE) and the 911 Emergency System to perform real-time tsunami threat analysis and thus generate information for eventual alerts. These real-time threat analyses use information generated in the above-mentioned processes.

Conclusion

Tsunamis are a rare threat, but they can be very destructive. The accelerated population growth in our coastal areas increases our vulnerability to them. The country needs to generate the tools to ensure that tsunamis are considered in all relevant instances, in all community preparedness and response plans, and all public or private institutions in coastal areas. More intense coordinated work among institutions is also required to further extend the reach of the scientific results obtained by SINAMOT, as well as extensive and continuous awareness campaigns to not forget a threat that could prove very costly to the country at any moment. Consequently, the country should allocate resources for this purpose, as it has been doing for several decades for seismic and hydrometeorological hazards, with excellent results.

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Contributions of coastal dynamics monitoring to land-use planning and disaster risk management: the Costa Rican Caribbean case

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Coastlines are areas of contact between the land and the sea, extending from the upper part to the lower part, as far as wave action reaches. These are some of the most dynamic environments on Earth and, therefore, they are very vulnerable to human coastal activities. In coastal areas, processes or events occur that may

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pose natural threats to their use and occupation, such as severe waves, extreme tides, flooding and the removal of sand that is not subsequently replenished (erosion). On the other hand, human activity generates environmental impacts that degrade or alter these natural environments. Some examples include solid pollution, liquid discharges, sediment flow interruption, sand extraction, compaction and alteration of sediments. Some of the reasons for this are the movement of people and vehicles, the construction of infrastructure such as homes and buildings for habitation or tourism, which lead to the elimination of coastal ecosystems and a decrease in biodiversity.

In the current context of climate change, other processes threaten the dynamic equilibrium of these areas, such as rising sea levels and altered storm patterns. In a practical sense, sea level is the baseline from which a variety of processes operate, such as the reach of tides on land and the advance of breaking waves towards land. The first leads to an increase in marine flooding along the coast, and the second, in the extent of storm surges over land. On the other hand, the increase in storm frequency and magnitude directly affects wave climate. Such sea level increases and changes in storm patterns have led to the appearance or worsening of erosive processes, particularly on sandy beaches, requiring monitoring to understand how coastal socio-natural systems are affected.

Maritime-Terrestrial Law No. 6043, which establishes an inalienable public zone of 50 m from the mean high tide line, has been generally respected in the Costa Rican Caribbean coastline. This regulation has favored conservation of coastal environments and allows maintenance of vegetation coverage behind the beach. In practice, it is a form of protection for the sediments that are part of the beaches. However, the current coastline retreat due to storm surges has brought both public and private infrastructure closer to the beaches, thus increasing their vulnerability to erosion, flooding, and sedimentation.

In a pioneering study, Barrantes and Sandoval (2018) identified eleven coastal erosion hotspots in the Costa Rican Southern Caribbean. This background led to measurements being taken on the beaches of that coastline to understand how erosion occurs and what implications it has for the beach, coastal landscape, and local communities; it also provides support for finding solutions. These measurements are also part of the solution-finding process. They were carried out in 2017 as part of two undergraduate and graduate theses on the beaches of Moín, Cieneguita and Gandoca. Subsequently, in 2018, the Environmental Geomorphology Program (PROGEA) of the Escuela de Ciencias Geográficas at the Universidad Nacional developed a monitoring project that covered, in addition to the aforementioned beaches, those of Cahuita, Puerto Vargas, Cocles, Manzanillo and Gandoca. Due to the interest of the National Commission for Risk Prevention and Emergency Attention (CNE) as well as the accumulated experience, the National Coastal Erosion Monitoring System (Sinamec) was created in 2020.

Preliminary results include the recording of the annual beach cycle. Although Costa Rica does not have climatic seasons as such, due to its geographical position, much of the swell reaching the Caribbean coast varies according to hemispheric seasons. This cycle begins with the loss of sediment because of the increase in wave energy during the hemispheric winter; thus, the beach narrows and develops a concave, or winter, profile. However, in hemispheric summer, wave height decreases, the beach recovers sediment, and usually grows to its maximum width and volume. But monitoring has shown that in the Costa Rican Caribbean coast, this occurs generally in the hemispheric autumn, possibly in response to waves generated during the hurricane season (Figure 8.1).

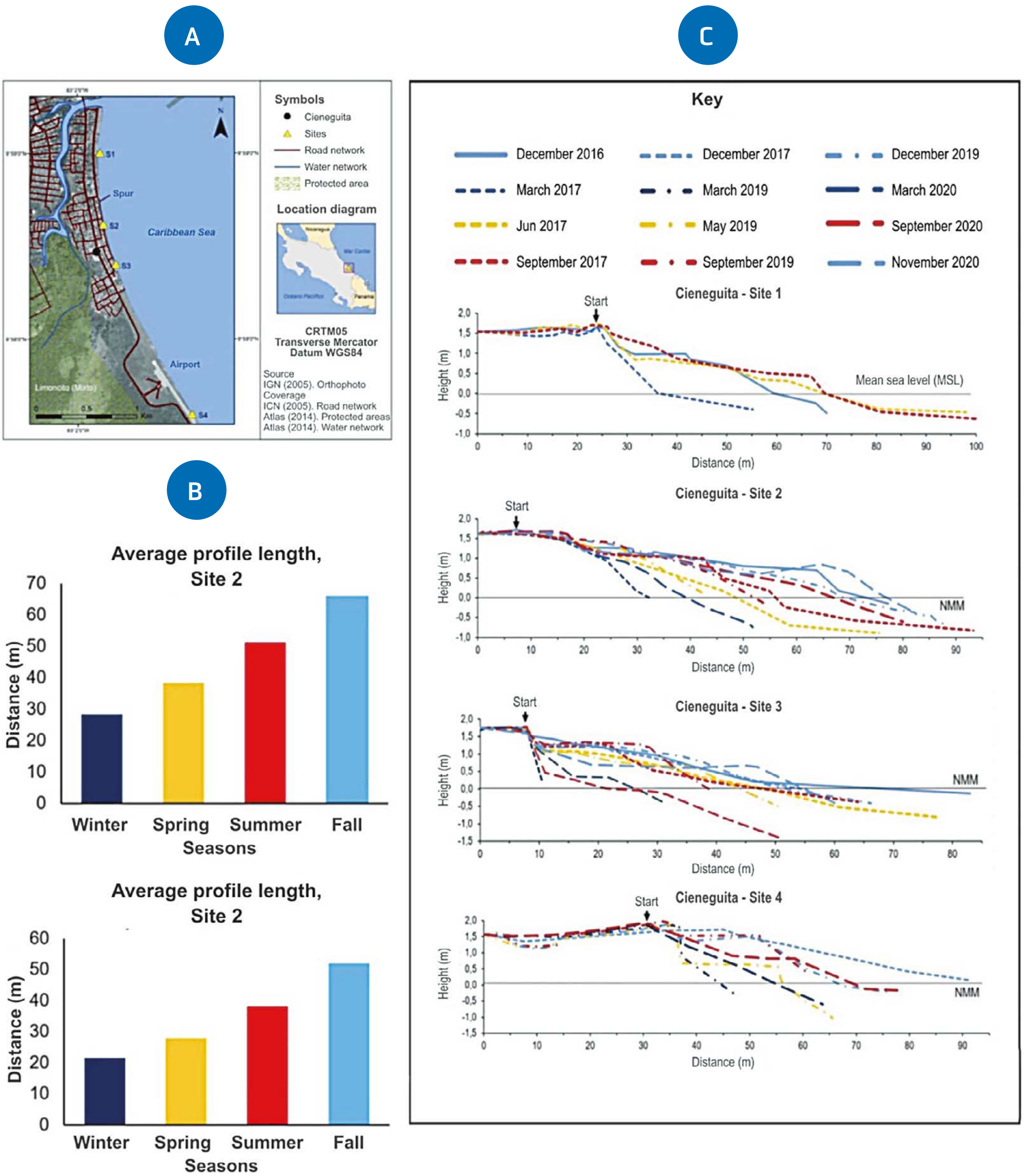

Figure 8.1. Seasonal changes of beach profiles. A) location of monitored sites between Cieneguita and Limón Airport, B) topographic profiles of the four monitored sites and C) seasonal beach changes at two Cieneguita sites.

Source: Modified from Barrantes *et al.*, 2021.

Understanding seasonal beach cycles and the morphological changes they cause is crucial for decision-making, especially with respect to land use, since any structure, such as trails or infrastructure for tourism, can be damaged during the hemispheric winter. In addition to its contribution to the management of tourism activities, this knowledge helps technicians from institutions and decision-makers avoid confusing this seasonal beach dynamic with actual erosion processes, where, over the long term, there is stability in the amount of sand removed.

Despite the above, during extreme wave events, sediment loss can reach a critical point that leads to the beach's inability to recover, with the resulting reduction in its emerged area (or dry beach), migration of the coastline inland, and the undermining of structures placed behind the beach (Castelle & Harley, 2020).In this sense, with monitoring it is possible to differentiate between permanent erosion processes and seasonal changes or beach cycling. For example, the extreme swell that occurred in January 2020, with waves over 3 meters, caused a marked retreat of the coastline in Moín and Puerto Vargas and significant retreat of sediments from Cieneguita, Puerto Vargas, Negra, Cocles and Manzanillo beaches. This phenomenon caused significant erosion of several beaches, as evidenced by the presence of ridges of more than one-meter, exposed roots, fallen vegetation, and shortening of the beach (Figure 8.2), as well as affected businesses and homes (Barrantes *et al.*, 2020).

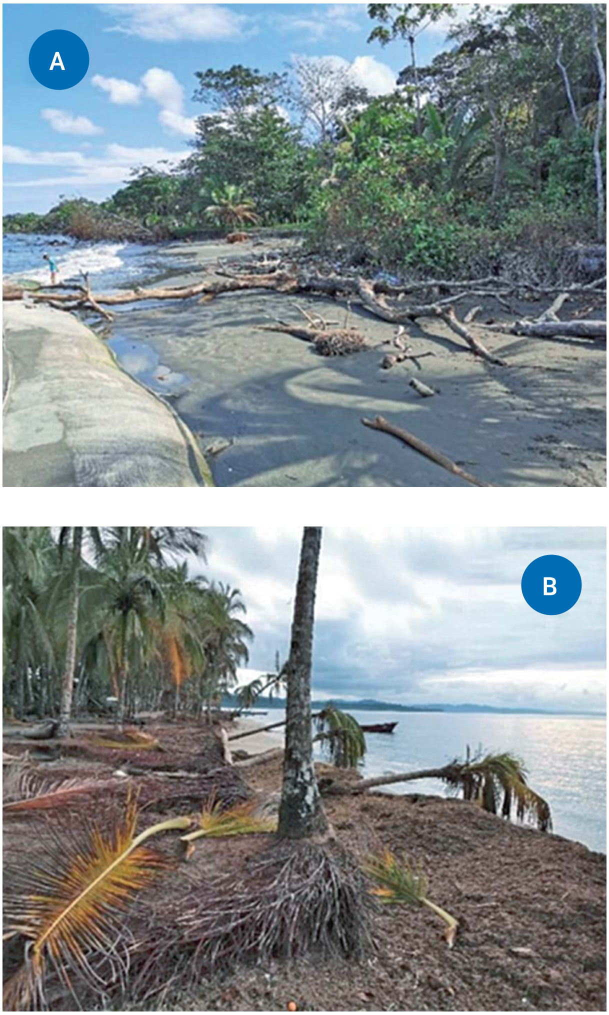

Figure 8.2. Effects of the January 2020 swell in the southern Caribbean of Costa Rica. A) Moín beach; note the retreat of the coastline. B) Fall of coconut trees and root exposure on Manzanillo beach.

Source: @Gustavo Barrantes, January, 2020.

The effect of this swell on the coast was evident in several topographic profiles, such as the one located in front of the Limón airport (Figure 8.3). In this sector, the swell caused a considerable loss of sediment between December 2019 and March 2020; over time, however, the beach recovered sand. The recovery was already evident in March 2023, in terms of beach volume and width. Monitoring allowed confirming that the reported swell, although having significant impact, did not represent a permanent erosion condition, since there was a subsequent recovery of the beaches.

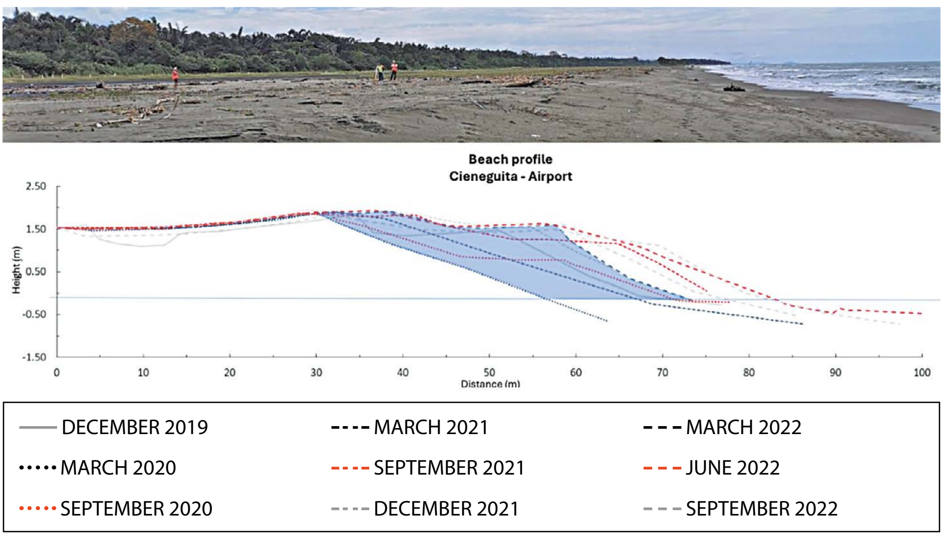

Figure 8.3. Analysis of changes in the topographic profile of Cieneguita beach, in front of Limón airport. Upper image: photo of the profile site, on 28/01/2020. Lower image: Profile overlay between December 2019 and December 2023. Note, in light blue, the area that was later recovered.

Source: Data from Progea.

In this sense, permanent monitoring is recommended to determine the inflection point at which a certain wave energy withdraws sand, exceeding the recovery capacity of the beaches. For each case, intervention actions should be evaluated to preserve the resource, considering tourism, commercial, and residential uses. Although the beaches in Moín and Cieneguita recovered, there was a direct impact on the land due to surge penetration, sand removal, and coastal retreat. For this reason, establishing a buffer zone between the infrastructure and the beach, preferably covered by natural vegetation, will serve as the first line of defense against extreme events such as these, beyond the 50 m established in the Maritime Terrestrial Zone Law.

Similarly, monitoring changes in the coastline allows establishing rates of retreat (erosion), advance (accretion), and stability of the coastline. After calculation and dissemination using a geo-viewer (https://www.geo.una.ac.cr/index.php/progea), it enables communities and entities involved in land-use planning and disaster risk management to learn about the speed and trend of loss or gain processes occurring on each beach. For example, this method allowed for determining that a section of Manzanillo Beach, just under 500 meters, registered a retreat of 23 meters between 2005 and 2016, with an erosion rate of 2.1 meters per year (considered intense), despite being a site protected by a reef (Barrantes & Sandoval, 2021).

Unmanned aerial vehicles (drones) have helped update the erosion rate and evaluate the level of exposure of public and tourist infrastructure, as well as housing (Figure 8.4). These measurements show that erosion acts with the same severity throughout the beach: for example, a sector located by the Manzanillo soccer field, retreated 40 m in 16 years, while it retreated only a few meters in the same period in other nearby sectors.

Figure 8.4. Photomosaic constructed from photogrammetric flight at Gandoca beach. This sector shows intense erosion; note the proximity of infrastructure such as urban facilities, including tourist establishments (such as hotels and restaurants), as a result of the receding coastline.

Source: Data from Progea.

The coastal areas of the South Caribbean of Costa Rica are geomorphologically dynamic and some of them, because of their scenic beauty and quality of their beaches, are used for tourism activities (such as Cahuita, Manzanillo and Cieneguita) or urban development processes mostly associated with tourism infrastructure (such as Puerto Viejo or Cocles). Thus, land management and territorial planning are two aspects that should be integrally considered in order to achieve sustainable use of beach resources.

In Costa Rica, territorial planning is defined as the spatial expression of social, environmental and economic policies; as well as an administrative exercise and national policy, based on coordinated and articulated decision-making, to guarantee adequate development of human settlements, integrated management of natural resources and economic development in the territory (MIVAH, 2012). When focusing on coastal areas, planning them through coastal regulatory plans is complex because there is a broad legislative and regulatory framework where various institutions have direct influence over these spaces (Table 8.1). This institutional and legal framework is intended to guide orderly and sustainable coastal development. However, the dynamism of these areas, as has already been shown, exceeds the speed with which laws or regulations adjust to new realities. For example, current problems associated with coastal erosion create risk conditions, which translate into direct impacts on ecosystem services and resources, tourism, and infrastructure. Therefore, Disaster Risk Management through Territorial Planning is essential to reduce conditions of exposure and vulnerability of coastal communities and promote resilience mechanisms. In this sense, the question arises: what is the contribution of coastal erosion monitoring to territorial planning and disaster risk management?

Table 8.1. Summary of institutions, laws that empower them, and their responsibilities in the development of coastal regulatory plans in Costa Rica.

Institution	Reference Law	Competencies
Municipalities	– Law on the Maritime Terrestrial Zone (Law No. 6043). – Urban Planning Law (Law No. 4240)	– Prepare and approve regulatory plans in its jurisdiction, including coastal zones. – Administer and grant concessions in the maritime terrestrial zone. – Build roads to guarantee access to public areas. – Collect and receive canons on concessions.
Costa Rican Institute of Tourism (ICT)	– Law on the Maritime Terrestrial Zone (Law No. 6043). – General Tourism Law (Law No. 1917).	– Draft the general plan for land use in the maritime terrestrial zone, in accordance with national development priorities. – Declare tourist or non-tourist zones in the maritime terrestrial zone. – Approve plans for urban or tourist developments that affect the maritime terrestrial zone. – Participate in planning and management of tourism in coastal areas, ensuring compatibility with municipal regulatory plans.

Institution	Reference Law	Competencies
National Institute of Housing and Urbanism (INVU)	– Law on the Maritime Terrestrial Zone (Law No. 6043) – Law of the National Institute of Housing and Urban Planning (Law No. 1788).	– Establish technical guidelines for urban development. – Review and approve regulatory plans prepared by municipalities, including coastal areas. – Approve plans for urban or tourist developments that affect the maritime terrestrial zone.
Ministry of Environment and Energy (MINAE)	– Organic Law on the Environment (Law No. 7554).	– Regulate and protect the environment. – Supervise environmental impact assessments through the National Environmental Technical Secretariat (SETENA). – Establish environmental policies to be considered in regulatory plans. – Delimit protection zones for certain marine, coastal, and wetland areas, which will be subject to development and management plans.
National System of Conservation Areas (SINAC)	– Organic Law on the Environment (Law No. 7554). – Biodiversity Law (Law No. 7788).	– Manage protected areas and national parks. – Conserve biodiversity in coastal areas. – Guarantee the sustainable use of natural resources within its scope of action.

Source: Prepared by the authors from a comparative analysis of Costa Rican laws No. 6043, 4240, 1788, 1917, 7554 and 7788.

To answer the previous question, it is important to emphasize the contribution that monitoring provides to risk management and land use planning. The technical and scientific rigor of the data enables decision-makers (local governments and the National Emergency Commission (CNE) along with the private sector and communities) to promote mitigation mechanisms, both structural and otherwise, to understand this dynamic process. It also allows them to rethink risk management with a long-term prospective approach, particularly in areas where tourism and urban growth generate pressures, often without considering the existing threats. Considering the above, significant synergies have been created with stakeholders through the PROGEA, for example, in the Talamanca canton, with the CNE and the Amistad Caribe Conservation Area (ACLAC). With the financing they provide, projects such as partial funding for monitoring, training to carry out complementary monitoring, workshops for presenting and interpreting results, and promoting access to and use of data are materialized. This is the foundation for identifying exposed and, therefore, vulnerable elements (ecosystems, infrastructure, housing) and for making recommendations regarding land use planning.

In summary, coastal erosion monitoring is an essential tool for land use planning and disaster risk management in these areas, since the information generated and made available can be used to consider coastal dynamics and the changes that are affecting coastal systems as a result of climate change and variability, for incorporation into land use planning processes, as well as to decide how to protect ecosystems and exposed infrastructure when required. Although Costa Rica has a robust legal and regulatory framework, it is necessary to generate public policies that consider the natural variability of this environment, its fragility and the changes it is currently experiencing, in order to achieve sustainable development in these areas.

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Using seismology as a tool for monitoring ocean dynamics and climate change

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Oceans make-up more than 70% of the planet's surface (NOAA, 2024) and play a key role in shaping global climate, biodiversity, and weather patterns. For this reason, ocean dynamics have long been a topic of interest in several scientific fields. In recent years, the accelerating pace of climate change (Minière *et al.*, 2023) has highlighted the need to develop innovative and accurate tools to monitor ocean conditions and their impacts on the environment, for which methods from other sciences can be applied. For example, seismology, traditionally used to investigate earthquakes, volcanoes and tectonics at different scales, has emerged as a useful tool in this context. By analyzing the random field of seismic waves, also known as ambient seismic noise, it is possible to monitor wave interactions with the Earth's crust and to track changes in ocean energy patterns, which are closely linked to climate processes such as hurricanes, coastal storms, and sea level variations (Gualtieri *et al.*, 2018).

The analysis of the random field of seismic waves, generally referred to as seismic interferometry (Snieder and Larose, 2013), is a method that takes advantage of the natural interactions between ocean waves and the Earth's crust, producing a wave field referred to as micro-seismic band I or II (Ardhuin *et al.*, 2011). This wavefield propagates isotropically across the Earth's surface and is recorded by seismological stations anywhere in the world (Figure 9.1). Although the primary use of seismic data is to detect and locate earthquakes, the constant background noise generated by ocean waves, especially in the microseismic band II (periods of 1 to 10 seconds), provides valuable information about oceanic and environmental conditions (Larose *et al.*, 2015).

Recent research (Chaves and Schwartz, 2016; Núñez *et al.*, 2020) has shown that, by cross-correlating environmental seismic noise, it is possible to reconstruct Green's functions (response to a transient stress pulse in the Earth's crust; for example, those originated by earthquakes, hurricanes, among others) between pairs of stations. Green's functions allow monitoring changes in the Earth's internal structure, also caused by external processes such as waves or storms. This method has proven to be useful in coastal regions where ocean dynamics are closely related to climatic conditions. Seasonal variability in ocean-coastline interactions, as identified in seismic data, can reveal patterns related to monsoons, hurricanes, the effects of El Niño or La Niña, and other meteorological systems that significantly impact ocean circulation and energy distribution.

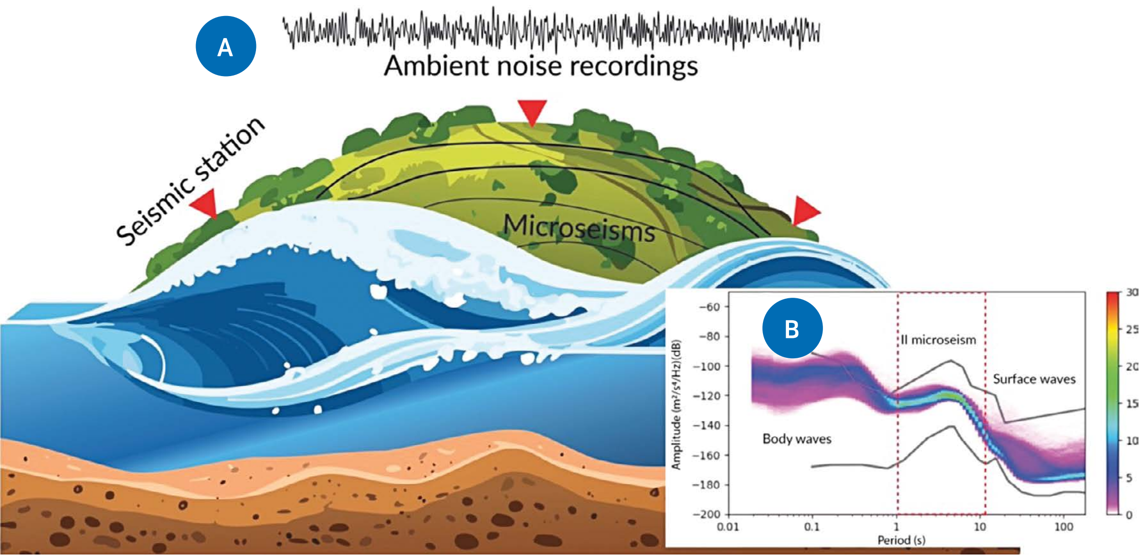

Figure 9.1. a) The illustration shows the generation of ambient seismic noise through the interaction of oceanic activity with the earth's crust. b) The full spectrum and frequency distribution of seismic energy recorded daily at a given seismic station. In this figure, the colors indicate the intensity in decibels. The upper and lower solid lines indicate the average upper and lower limits observed worldwide. Microseismic II is in the period range of 1 to 10 s, as marked in the red rectangle.

Source: Own elaboration.

As global temperatures continue to rise due to climate change, ocean dynamics are expected to undergo significant changes. For example, the frequency and intensity of hurricanes and coastal storms are expected to increase significantly in coming years (Aumann *et al.*, 2008), altering energy patterns in ocean dynamics and, consequently, in seismic signals recorded by seismological stations along the coast. Sea level rise, a direct consequence of global warming, will also affect coastal regions and potentially transform marine ecosystems that depend on stable oceanographic conditions. Seismology, and particularly the use of seismic interferometry (Schuster, 2009), offers a promising opportunity to track these changes, especially in regions where traditional oceanographic instruments, such as buoys, may be scarce or difficult to maintain.

Seismic interferometry is a suitable methodology for developing regions, such as the Costa Rican South Pacific, where the Observatorio Vulcanológico y Sismológico of Costa Rica (Oviscori) of the Universidad Nacional (UNA) operates a permanent broadband seismic network (Figure 9.2); as a result, dynamic interactions between the ocean and the Earth's crust can be observed throughout the year. In this region, the Golfo Dulce and the adjacent Osa and Burica peninsulas experience seasonal wave variations. These variations can be monitored by ambient seismic noise. By analyzing the correlation (or similarity) coefficients of Green's functions over time, changes related to the sources that modulate ocean dynamics, as well as their interactions with the crust, can be detected. This method provides a non-invasive and cost-effective means of monitoring the ocean, which could become increasingly critical as climate change exacerbates weather patterns and impacts coastal regions.

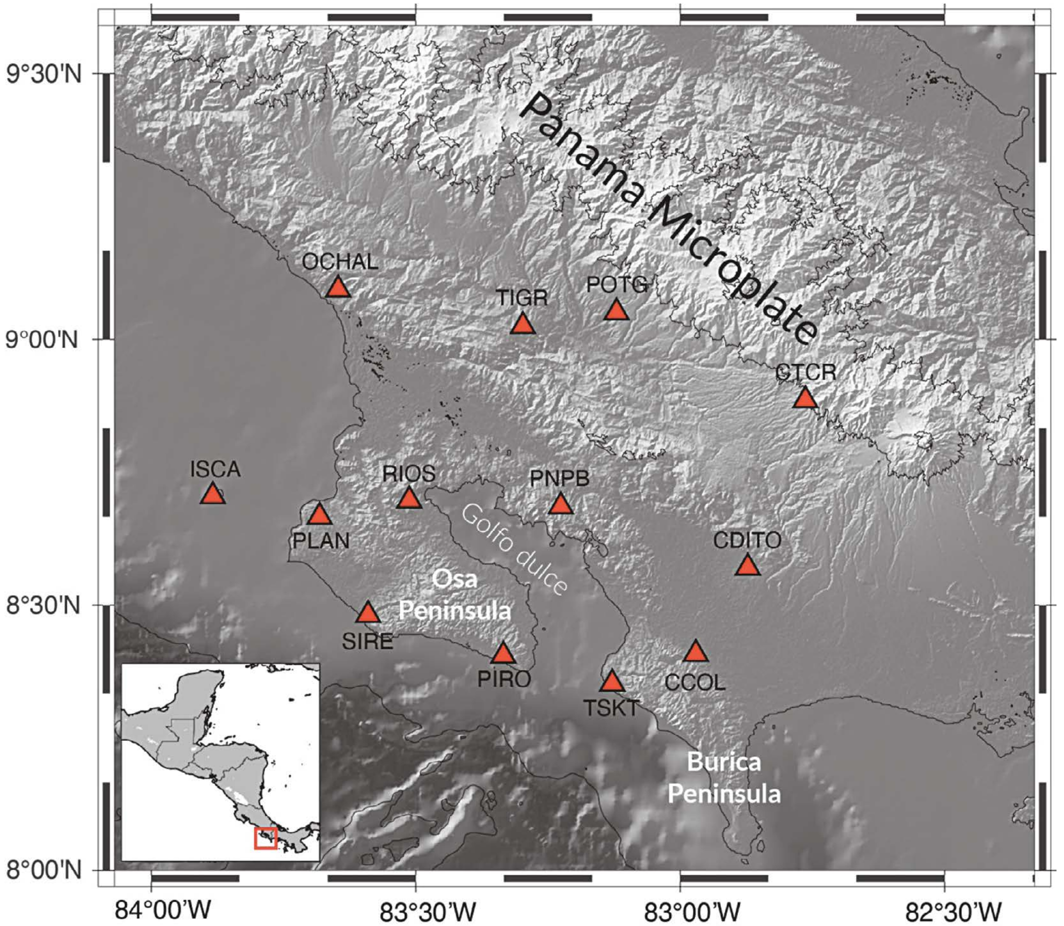

Figure 9.2. Map showing the spatial distribution of seismological stations (triangles) operated by the Observatorio Vulcanológico y Sismológico of Costa Rica (OVSICORI) in southern Costa Rica.

Source: Own elaboration.

Moreover, the environmental implications of changes in ocean dynamics involve more than just physical processes. Marine ecosystems, which depend on the stability of oceanic conditions, are likely to be affected by changes in temperature, salinity and ocean currents. These highly biodiverse ecosystems are vital to the livelihoods of many coastal communities, including those in the Costa Rican South Pacific. Seismology, by providing a continuous record of terrestrial vibration associated with ocean dynamics, can provide early warning signals as a timely and informed response to stressors and challenges posed by climate change.

In the coming years, as the effects of climate change become more pronounced, seismology in ocean monitoring is likely to gain greater importance. This is particularly due to its ability to provide real-time data on oceanic conditions, combined with its global coverage through existing seismic networks, making this methodology a powerful tool for both scientists and policymakers. By integrating seismic data with other environmental surveillance systems, such as satellite observations, oceanographic buoys, and other monitoring systems, it may be possible to develop a more comprehensive understanding of changes occurring in the oceans and their environmental implications.

How can seismic interferometry and, in particular, ambient seismic noise be used for ocean monitoring? Since ambient noise is formed from surface waves, produced by the interaction between ocean waves and the earth's crust, seismologists can rely on the mechanical properties of these waves, such as dispersion, to analyze not only plausible changes in the earth's crust, but also changes in the sources of ambient noise, including interactions between the ocean and the crust. Seismologists can decompose the surface wavefield into different frequency ranges, each of which will have 1) sensitivity to different depths and 2) dependence on noise sources and their variability over time.

Observations: seasonal and annual variability in the Costa Rican South Pacific

An example of how seismology can be used for ocean and climate monitoring is as follows: the cross-correlation of ambient seismic noise was calculated between the annual records of all station pairs shown in Figure 9.2. For this, the period band of 1 to 3 seconds (0.333 to 1 Hz) was used, as it is more sensitive to ocean wave interactions with the coastline over short periods. For all station pairs, we extracted daily Green's Functions (GFs), between the years 2019 and 2023. These GFs contained all information related to the state of health of the shallow lithosphere for each day. To retrieve the average state of the crustal vibrations in the South Pacific of Costa Rica and its sources, a reference Green's Function was reconstructed for the period (2019-2023), simply by linearly averaging the daily GFs. In addition, the daily GFs behavior was analyzed by measuring the correlation coefficient (or similarity) with respect to the reference GF.

Figure 9.3 shows an example of the results obtained between the CCOL-RIOS pair of stations. The surface wave field trajectory between these stations crosses the Golfo Dulce, as shown in Figure 9.2, and therefore, the seismological information traveling between this station pair contains all the data related to the ocean floor and the coastline in the region. Transient changes in the ambient noise source or crustal-structural composition or combination of both will result in a reduction in the correlation coefficient between the daily GFs and the reference GF. The results show seasonal instability effects in ambient noise sources in the South Pacific, reflected, for example, as negative interference appearing annually, always between January and May, in the interferogram (panel A) of Figure 9.3.

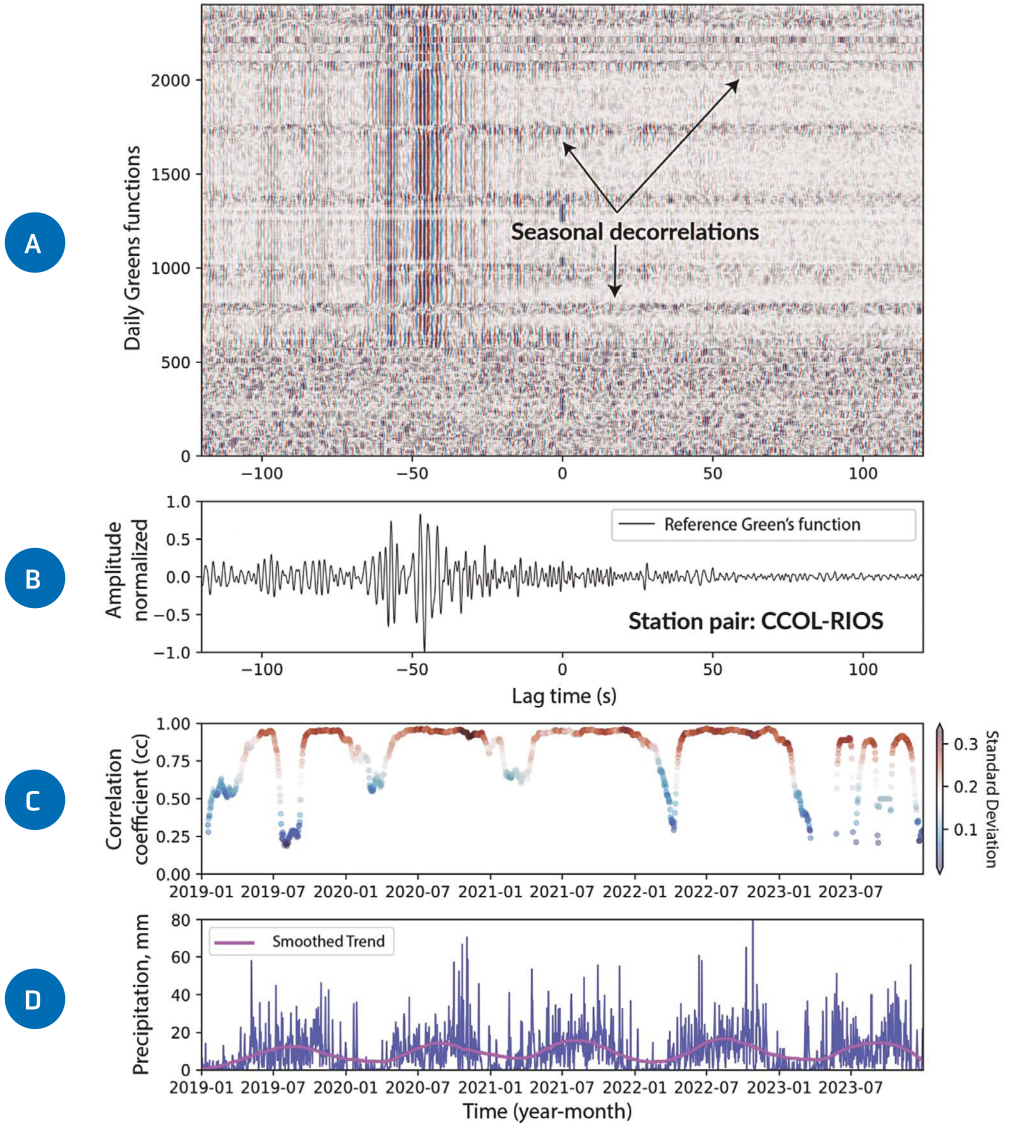

Figure 9.3. The figure shows cross-correlation results for ambient seismic noise between CCOL and RIOS stations. Panel A) shows the interferogram of daily Green's functions. Each line represents the daily crustal state of the Earth's crust in

the period from 1 to 3 s. The occurrence of negative interference is clear, showing horizontal lines disrupting the blue and red color pattern. Panel B) shows the reference Green's function, obtained after averaging daily GFs for the whole study period (2019-2023). Panel C) shows the cross-correlation coefficient as a function of time, color-coded by standard deviation. Panel D) shows the precipitation table for the same analysis period. The magenta line highlights the smoothed trend during the rainy and dry seasons.

Source: Own elaboration.

The seasonal effect is also reflected in the temporal evolution of the correlation coefficient (CC), which decreases by at least 30% each year since 2019 (see panel C in Figure 9.3). The reduction in CC corresponds temporally with a seasonal reduction in precipitation (panel D in Figure 9.3), and hence with a decline in the number (or frequency) of storms and in the interaction of the ocean with the coast in the form of short-period waves. Figure 9.4 shows the correlation index, given by the 1-CC result, as a function of time and includes more pairs of stations located on the Osa and Burica peninsulas. The results show that seasonality is not restricted to one or a few station pairs, but rather it is a general condition for the entire South Pacific; furthermore, it is not related to instrument failures. The black line in Figure 9.4 reflects the average behavior in the region, where there were clear changes in ambient noise sources between January and May, with peaks in the decorrelation during April of each year.

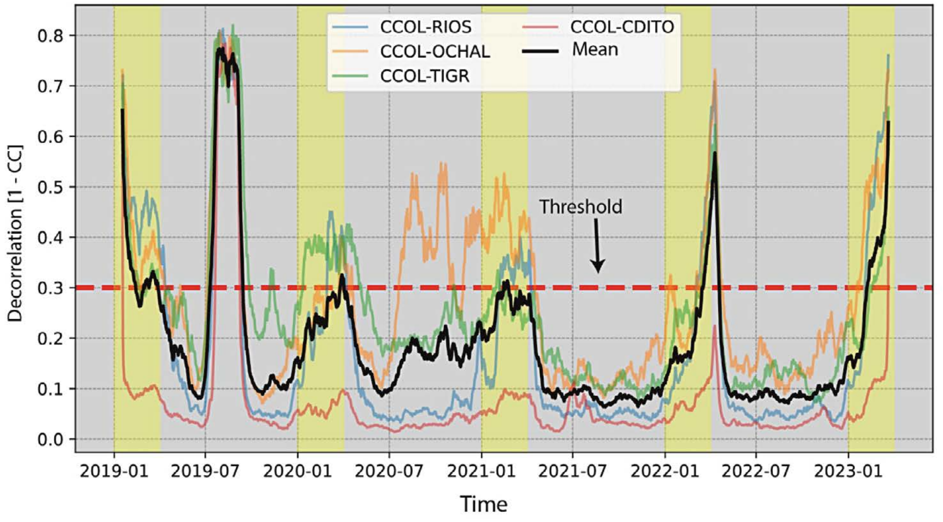

Figure 9.4. Decorrelation of the empirical Green's function over time for a selected number of seismic station pairs (solid-colored lines) distributed along the Osa and Burica peninsulas in the South Pacific of Costa Rica. In the figure, the thick black line represents the mean decorrelation observed between all station pairs. The dashed red horizontal line highlights the 30% increase in decorrelation. Yellow rectangles highlight the period between January and April of each year, where the decorrelation reaches its seasonal peak. The increase in decorrelation observed between late June and August 2019 was generated by the Mw=6.5 Port Armuelles earthquake that occurred on June 26 at 05:23:48 UTC and its aftershock sequence.

Source: Own elaboration.

Correlation coefficient maps (Figure 9.5) for the dry and rainy seasons revealed significant annual and seasonal variability in seismic waveform similarity, with notable patterns emerging in relation to climatic and oceanic conditions in the area. For example, 2019 exhibited the lowest minimum CC values during the dry and rainy seasons, as indicated by the prevalence of green and yellow lines on the maps. The variability in CC during this year could be attributed to less consistent climatic conditions, which may be influenced by localized weather patterns, deep ocean noise, and changes in the interaction of short-period waves with the coast.

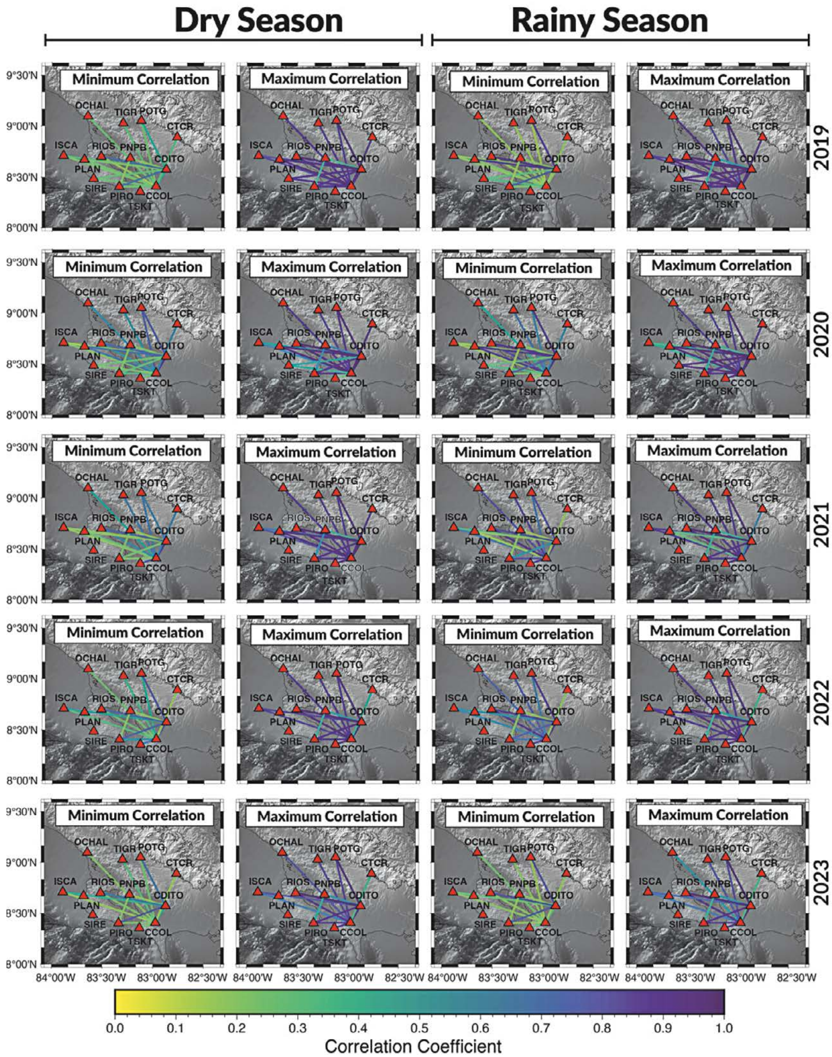

Figure 9.5. Seasonal distribution of minimum and maximum CC values between pairs of stations in the Costa Rican South Pacific, obtained through annual cross-correlation of ambient seismic noise. In the figure, each row corresponds to the comparison of CC between the dry and rainy seasons for the years 2019-2023, respectively.

Source: Own elaboration.

The decorrelation amplitude identified is similar for years 2019, 2022 and 2023, with a mean value of 0.65, while for years 2020 and 2021 the mean decorrelation index is 0.31. This may be related to the activity caused by La Niña effects in that time period. La Niña conditions typically increased precipitation in the region, particularly in the central and southern Pacific areas, resulting in persistent rainfall, particularly during the latter part of the rainy season. In 2021, heavy rainfall was exacerbated by the interaction of the Intertropical Convergence Zone (ITCZ) and the passage of tropical waves, which triggered weather alerts in parts of the South Pacific and resulted in warnings for possible flooding and landslides due to soil saturation.

On the other hand, *La Niña* tends to increase both precipitation and storms, which in turn causes changes in ocean depths that favorably influence seismic signals due to changes or stability in the ambient noise wave field. A lower decorrelation index (higher CC) during January-May of 2020 and 2021 suggests that seismic waveforms were more consistent, similar, and stable. The effect of *La Niña* could generate more stable noise conditions that remained relatively constant over time, reducing variability in seismic signals and maintaining waveform similarity during the transition from the rainy season to the dry season.

Conversely, a higher decorrelation index (lower CC), during January-May 2019, 2022, and 2023 suggests greater variability in seismic waveforms, possibly due to less stable climatic conditions or more marked climate transitions. In these years, which were not as strongly affected by La Niña, seismic signals could have been influenced by sporadic or less predictable climatic factors, such as localized storms, fluctuating ocean activity, or varying levels of soil saturation. These factors introduced more variability in seismic signals, making them less correlated and therefore leading to higher decorrelation values.

Furthermore, 2020 and 2021 exhibited consistently higher CC values during both the dry and rainy seasons, with the minimum CC values being significantly higher in these years compared to 2019. This suggests more stable ambient noise conditions, which may be attributed to the La Niña phenomenon that affected the region during those years. La Niña brings steady rainfall and ocean activity, as mentioned above, generating stable noise sources and conditions in the surface crust that reduced noise variability and led to more consistent seismic waveforms. Higher CC values at several station pairs during these years reinforce a consistent and uniform noise environment during dry and rainy seasons. On the other hand, analysis of 2022 and 2023 revealed a return to more variable seismic waveforms, with lower minimum CC values identified during both seasons, particularly in 2023. The greater presence of green lines in these maps suggests greater dissimilarity in waveforms, likely due to less stable climatic conditions. Furthermore, these years did not experience the same La Niña influence as 2020 and 2021, thus showing greater variability in waveform similarity. However. the maximum CC values during these years remained relatively high, indicating that, despite the greater variability, there were still periods of high waveform similarity.

Discussion and conclusions

This study demonstrates that cross-correlation of ambient seismic noise is a powerful tool for monitoring dynamic interactions between ocean waves and the Earth's crust, particularly in regions that could be dramatically affected by climate change. By analyzing the temporal stability of the Green's Functions GFs, extracted from ambient seismic noise in the 1 to 3 s period band, seasonal variations that reflect the influence of oceanic and atmospheric conditions on the seismic wavefield were identified. The strongest variations occurred during the dry season (January-April) of each year, with correlation coefficients dropping by as much as 70% during this period. These reductions are associated with lower storm activity, coastal waves and overall wave energy, as confirmed by concurrent precipitation data. This temporal decorrelation underscores the sensitivity of seismic interferometry to climate changes, particularly in coastal regions where ocean dynamics strongly influence the ambient noise field.

Annual variations in 2020 and 2021 were particularly significant, where La Niña influence resulted in more stable ocean conditions, reflected in lower decorrelation indices compared to the more variable patterns observed in 2019, 2022, and 2023. La Niña generally unleashes increased precipitation and steady ocean wave activity, which likely contributed to more stable noise conditions and, in turn, more consistent Green's functions during these years. This finding is consistent with previous studies highlighting the impact of large-scale ocean-atmosphere interactions, such as El Niño and La Niña, on the seismic noise field (e.g., Gualtieri *et al.*, 2018). These results suggest that seismic interferometry can serve as an indicator for monitoring broader environmental and climatic phenomena, providing information on the effects of large-scale weather patterns on coastal dynamics.

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Physical oceanography for informed decision-making

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The study of coastal dynamics in Costa Rica has advanced in the past two decades due to various research programs that have allowed monitoring of oceanographic parameters on the Pacific and Caribbean coasts. These studies are based on observations made by a scientific team, with the integration of information from computational numerical models, which allows for a better understanding of the different hydrodynamic processes in gulfs, bays and estuaries in the country. This work not only enriches scientific knowledge but also provides key information for decision-making in coastal communities, contributing to the sustainable management of their resources.

This chapter discusses significant research experiences in coastal physical oceanography carried out by the Departamento de Física at the Universidad Nacional. Specifically, it presents two relevant research experiences in coastal oceanography carried out in the Gulf of Nicoya, in the Central Pacific, and in the Bay of Santa Elena, in the North Pacific. The Gulf of Nicoya (Figure 10.1, lower panel) is an estuarine system with complex hydrodynamics, in which activities of high socioeconomic value for Costa Rica are developed. On the other hand, Santa Elena Bay (Figure 10.1 upper panel) was designated as a marine management area (Minae, 2018). In both cases, the usefulness of coastal monitoring using high-tech tools for the benefit of coastal communities and local governments is analyzed.

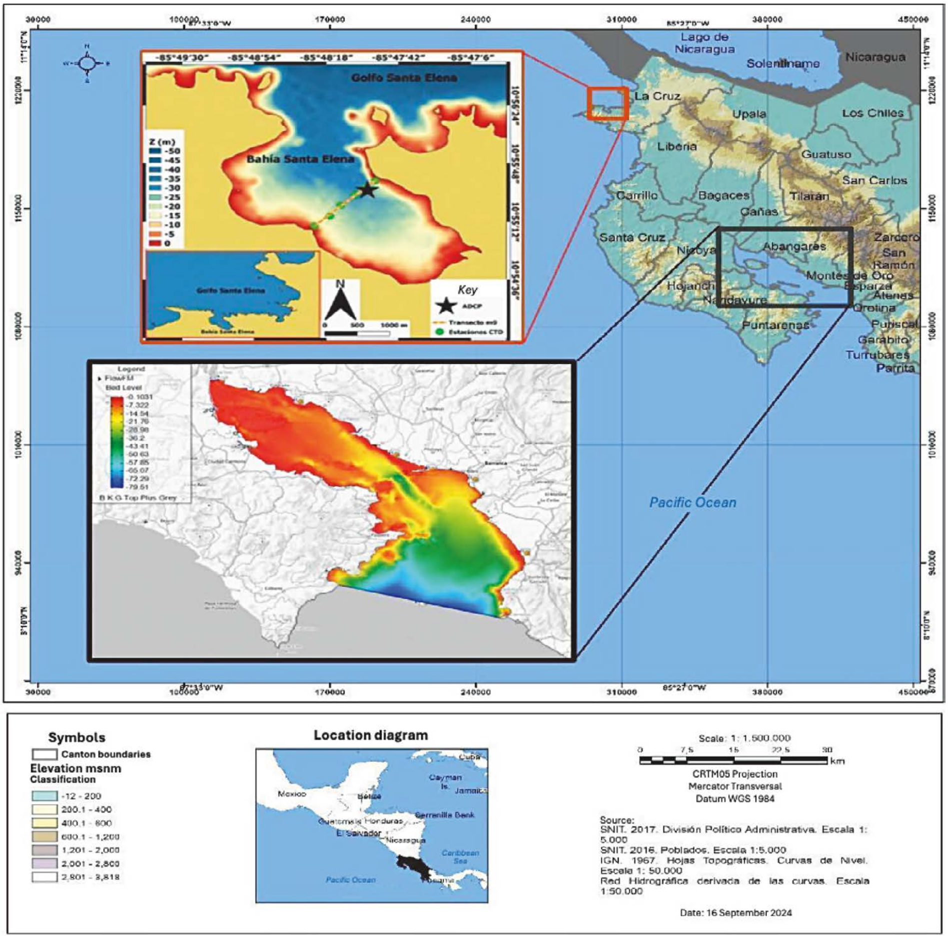

Figure 10.1. (Upper panel). Geographic location of Santa Elena Bay and its bathymetry in meters. Sources: Ortiz-Malavasi, E. (2014). Atlas Digital de Costa Rica. ITCR; bathymetric data from Tisseaux-Navarro *et al.*, (2021). (Lower panel). Geographical location of the Gulf of Nicoya and its bathymetry in meters interpolated on the Delft3D hydrodynamic model grid. The blue lines highlight open boundaries of the model where initial and boundary conditions are specified.

Source: Own elaboration.

In both experiences, specialized instruments were used to record field measurements through various methodologies. Two essential instruments used in oceanographic campaigns are the acoustic current meters (ADCP, Figure 10.2a-b) and the CTD multiparametric probes (Figure 10.2c). With the ADCP, the magnitude and direction of ocean currents along the entire water column are determined. The CTD records water temperature, conductivity (associated with salinity), turbidity, dissolved oxygen concentration, chlorophyll concentration, and water level, among other variables that provide a more detailed understanding of the physical characteristics of the different coastal water bodies under study. Both devices can be used in different ways. One option is to place them at fixed points on the seabed or somewhere along the water column, secured by buoys (anchors). This configuration allows obtaining time series of different variables for weeks or months, favoring continuous monitoring.

Another option is to conduct measurements from a moving boat along transects, allowing for the capture of spatial variations (both vertical and horizontal) of physical parameters. Furthermore, computational numerical models are also used as a valuable complement to field observations to understand the physical mechanisms governing coastal hydrodynamics. Numerical simulations of different scenarios combined with *in situ* measurements help to determine which factors influence the observed variability of the aforementioned parameters. This information is crucial for informed decision-making in economic activities developed in coastal areas, such as port navigation, mariculture, infrastructure planning, and fishing, among others.

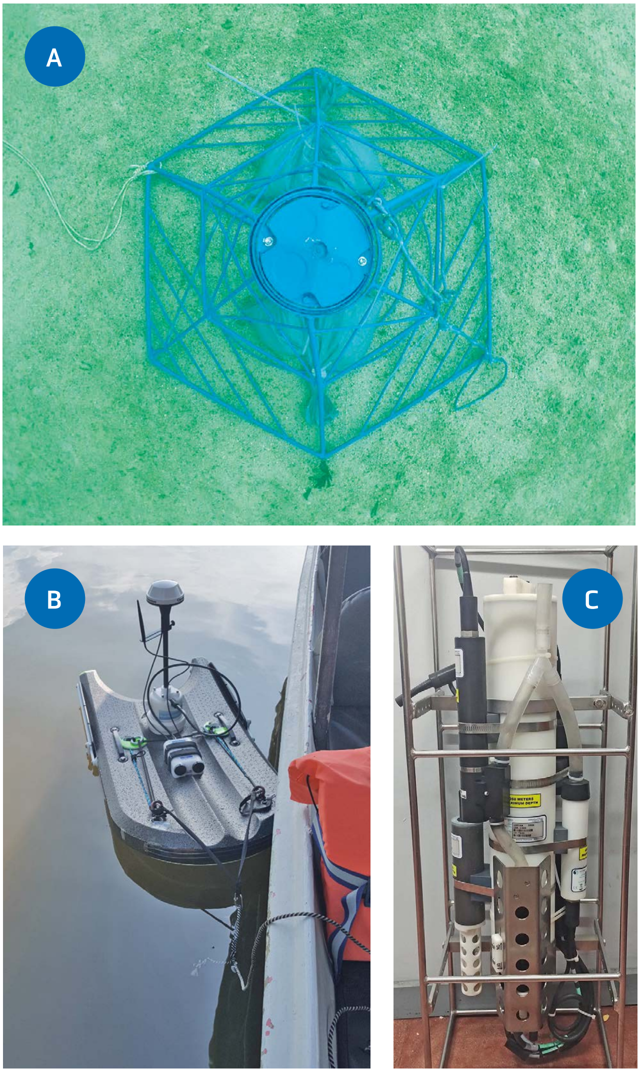

Figure 10.2. Instruments used in oceanography: Acoustic Doppler Current Profilers (ADCP) for use at (A) fixed points (anchorages) and (B) from a moving vessel; (C) Conductivity-Temperature-Depth (CTD) probe, which also incorporates dissolved oxygen, chlorophyll and turbidity sensors.

Source: Own elaboration.

Monitoring in the Gulf of Nicoya

The Gulf of Nicoya is the largest in Costa Rica. It is located on the Pacific slope and is the most important for the country from a socio-productive perspective, as it hosts two of Costa Rica's main ports: Caldera and Puntarenas. These ports are essential for tourism development and international trade. Additionally, the gulf plays a crucial role in the local economy through artisanal fishing and mariculture, both of which are key activities for coastal communities. From an oceanographic point of view, the Gulf of Nicoya behaves as an estuarine complex since several rivers drain into its basin: the largest being the Tempisque River, located in the internal gulf area, and the Grande de Tárcoles River in the outer region.

Since 2020, studies have been conducted to increase the temporal frequency of oceanographic variable sampling in the Gulf of Nicoya. The goal is to generate scientific evidence that can inform coastal communities and governments in their socio-economic and conservation activities. To achieve this, studies and measurements have been implemented using Acoustic Doppler Current Profilers (ADCP) and Conductivity-Temperature-Depth (CTD) sensors operated from a moving vessel along transects over a full tidal cycle (>12 hours). In previous studies, this process had not been conducted.

High-frequency measurements enable mathematical analysis to determine the residual or mean conditions of sampled data along across section in the Gulf of Nicoya. For example, this analysis helps separate tidal influence from water velocity observations, isolating net flow. It also allows for determining the speed and direction of objects or substances suspended in the water after several days of drifting and is useful for estimating the time of water renewal in an estuary. Instruments were also placed in fixed strategic locations (anchorages), allowing monitoring of temporal variations of hydrographic parameters along the entire water column, during both dry and rainy seasons.

Environmental conditions vary depending on the season. For example, during the rainy season, there is a greater contribution of fresh water and organic matter from the rivers to the sea. This phenomenon, combined with the weakening of the northeasterly winds, modifies marine currents, salinity levels, water levels, and oxygen concentration in the water. These changes are crucial for mariculture activities, since survival and growth of several species depend primarily on the environmental variations in the water.

Through continuous monitoring, variations in water level and ocean currents were quantified along the water column leaving or entering the Gulf of Nicoya, at a site located in the middle of the gulf (near the Puntarenas cruise ship dock). This monitoring has determined that fluctuations in both parameters are primarily driven by semidiurnal tides (with periods of around 12 hours) due to astronomical effects. However, a more in-depth analysis reveals additional factors influencing variability over periods exceeding 30 hours (subtidal component).

Similarly, decreases in salinity and dissolved oxygen in the water were identified, though they are not discussed in detail in this document. This occurs during the rainy season in the inner zone of the Gulf of Nicoya, near the mouth of the Tempisque River.

These variations need to be studied in detail because they can affect water quality, and therefore, survival and growth of marine species such as oyster farming.

Alongside field campaigns, the construction of a hydrodynamic computational numerical model of the Gulf of Nicoya was initiated to simulate the main oceanographic parameters in three dimensions: water level, current fields, temperature, and salinity. The goal is to use it as a decision-making tool, providing essential information on the possible behavior of oceanographic parameters within the gulf. This is useful for planning activities such as navigation, mariculture, fishing, and coastal management, among others.

The development of this model required *in situ* collection of oceanographic information for calibration and validation. During the model configuration process, a grid or worksheet was created in which the fluid dynamics equations are solved for each cell. This allows for an understanding of the temporal and spatial evolution of hydrographic variables. On this grid, bathymetry interpolations were performed to establish the spatial depth variations in the study area (Figure 10.1, lower panel).

Bathymetric observations come from both existing nautical charts and recent echosounder measurements. The bathymetry map (Figure 10.1, lower panel) shows that the deepest areas in the Gulf of Nicoya are located in the outermost part of the gulf and along the main channel found between Puntarenas and San Lucas Island. On the other hand, the shallowest zones (low depth) are in the inner part of the gulf, near the mouth of the Tempisque River, although the channels bordering Chira Island (the innermost island of the gulf according to Figure 10.1, lower panel) show greater depths compared to their surroundings.

So far, the model has successfully simulated water level variations in the inner, middle, and outer zones of the Gulf of Nicoya. Using water level data recorded during the rainy and dry seasons by a pressure sensor located at the Puntarenas cruise ship dock, the model's performance was calibrated and validated in the middle zone of the gulf. This process correctly explained the observed behavior in more than 97% of cases, demonstrating a satisfactory correspondence between measured water levels and those simulated by the model.

Similar results have been obtained for the inner zone (Chira Island) and the outer zone of the gulf (Herradura). Model simulations were performed with twenty vertical layers and include the main tidal constituents, wind simulations from the National Meteorological Institute of Costa Rica, using the WRF-2 model (Numerical Weather Models - IMN, n. d.) and flow rates of the main rivers draining into the Gulf of Nicoya.

Currently, work is being done on calibrating and validating the model for ocean currents, salinity and temperature by comparison with field observations obtained at different sites in the gulf. Once the model is calibrated and validated for all variables, it will be very useful not only for understanding the physical mechanisms that govern the variability of oceanographic parameters, but also for decision-making by port authorities and local governments in coastal areas regarding safe navigation and efficient docking of ships in ports.

In addition, the model will be a key tool in planning construction of coastal infrastructure, monitoring fuel spills, tracking harmful algal blooms, and analyzing sediment plumes during dredging activities. It will also assist in selecting suitable sites for commercial mariculture activities and identifying flood-prone areas caused by extraordinary increases in water levels, among other applications.

Monitoring in Santa Elena Bay

Climate in the Costa Rican North Pacific includes a dry season from November to April, characterized by low precipitation and increased intensity of northeasterly winds. These strong winds form a wind jet that interacts with the topography around Lake Nicaragua in northern Costa Rica and southern Nicaragua and is called the "Papagayo jet" (Chelton *et al.*, 2000; Clarke, 1988).

The rainy season extends from May to October and is characterized by an increase in precipitation and a decrease in the northeasterly winds. However, between July and August a period called "*canícula*" or "*veranillo*" (brief summer) reduces precipitation due to an increase in the intensity of the northeasterly winds compared to other rainy season months (Amador, 1998).

Santa Elena Bay (SEB) is on the North Pacific Coast of Costa Rica. It is a semi-enclosed coastal system adjacent to the Gulf of Santa Elena (Figure 10.1, upper panel). The bay is important to local communities due to its tourism and fishing potential (Villalobos-Rojas *et al.*, 2014). To promote the conservation and sustainable use of the area's marine resources, the SEB was declared a Marine Management Area in June 2018 (Minae, 2018). Additionally, the SEB has an average depth of 15 meters and a channel extending from northwest-to-southeast (Tisseaux-Navarro *et al.*, 2021) (Figure 10.1, upper panel). The tidal flow entering the system propagates from the Pacific towards the Gulf of Santa Elena and shows an average tidal range of 2.3 m and 2.7 m in syzygies (Lizano, 2006; Tisseaux-Navarro *et al.*, 2024b).

The Departamento de Física started its work at SEB with two measurement campaigns at the end of August and October 2019. During these campaigns, ocean currents were measured along a transect perpendicular to the bay's main channel using an acoustic Doppler current profiler (ADCP), deployed from a moving boat to profile the entire water column (Figure 10.2b). Additionally, vertical profiles of temperature, chlorophyll concentration, dissolved oxygen, and salinity were taken at six stations along the transect (Figure 10.1, top panel) using a CTD probe.

The CTD had a sampling frequency of 4 Hz and was slowly submerged at each point until reaching the seafloor. Only the downward-cast data were used for analysis. These measurements revealed that under conditions of low precipitation and weak winds, BSE exhibits an inverse estuarine circulation (Tisseaux-Navarro *et al.*, 2021). This means that water flows inward through shallow areas and outward through the deep channel. Tisseaux-Navarro *et al.* (2021) suggest that this particular circulation is not persistent year-round, and that weather condition variability may influence oceanographic dynamics within the bay. This result is noteworthy because coastal bodies exhibiting reverse circulation have a reduced capacity to evacuate fluxes, which has significant implications for water quality (Tisseaux-Navarro *et al.*, 2021).

During the dry season, conditions of increased northeasterly winds trigger surface water cooling events in the area. When these winds intensify, they displace the warm surface water away from the coast and allow upwelling of cold, nutrient-rich water in the surface layer (Ballestero and Coen, 2004; McCreary *et al.*, 1989; Vargas, 2002). However, these cooling events also occur during the rainy season, specifically between July and August when the wind intensifies during the "*veranillo*" (Tisseaux-Navarro *et al.*, 2024a).

During 2021 and 2022, a 500 kHz ADCP current meter was anchored on the seafloor at 30 m depth (see black star in Figure 10.1, upper panel). At the same location, temperature sensors were placed at 5-meter intervals from the bottom to near the surface. Measurements taken from June to July 2021 and 2022 recorded cooling events during the "Veranillo" in Bahía Santa Elena.

Tisseaux-Navarro *et al.* (2024a) explained that increasing northeasterly winds cause cooling of the Gulf of Santa Elena waters, which in turn lowers the temperature in the SEB. When the winds cease, a pulse of warm flow (relaxation flow) heads towards the coast and enters the bay, altering circulation patterns and increasing water velocity magnitudes. Relaxation flows entering the SEB double the magnitudes of subtidal currents (with periods greater than 24 hours) during non-event periods.

The authors suggest that these pulses may play an important role in water renewal within the bay and that these events are likely to influence biological processes in the area. Understanding how these flows influence ecological dynamics, species distribution, and overall ecosystem health will be crucial to gain a better perspective on the interaction between physical processes and biotic components of the bay (Tisseaux-Navarro *et al.,* 2024a).

The importance of oceanographic measurements and their influence on organisms inhabiting SEB has already begun to be observed in a study carried out between LAOCOS-UNA and the Center for Marine Science and Limnology Research (CIMAR) at the Universidad de Costa Rica (Tisseaux-Navarro *et al*., 2024b). Two commercially important fish species were studied: Red snapper *(Lutjanus colorado*) and Dog snapper *(Lutjanus novemfasciatus*). The analysis found that the number of fish at the site depended on the tide.

The rising water level during high tide allows fish to access inner mangrove areas where they find shelter and food (Sheaves, 2005). As the water level drops with the tide, the fish leave the mangrove but remain in nearby areas, waiting for the tide that will enable them to re-enter (Tisseaux-Navarro *et al*., 2024b). This study highlights the importance of incorporating oceanographic factors into species management strategies and emphasizes the crucial role of biological monitoring in coastal regions.

It is crucial to continue hydrographic studies in the area, considering the Costa Rican government's intentions to establish a port in this bay (Arias, 2016). Such a development could pose a threat to the conservation of all species in the ecosystem if the variability of ocean currents and water levels is not considered in coastal management planning and decision-making within the bay. Therefore, understanding the hydrographic properties of the bay help mitigate impacts on water quality and biological communities.

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PART IV
Health and productivity

Responsible fishing: A contribution to improving the quality of life of inhabitants in coastal areas of Costa Rica

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Creation and importance of Marine Protected Areas (MPAs)

In 1963, the Cabo Blanco Absolute Natural Reserve (RNACB) was the first Protected Area (PA) established in Costa Rica (Executive Decree No. 10 of October 21, 1963); it covers a total of 3,057 hectares (ha), of which 1,369 ha are terrestrial, and 1,688 ha are marine; representing around 55% of the total PA (SINAC, 2023). Since the creation of this PA, the country has been active in natural resource conservation, mainly by generating Marine Protected Areas (MPAs) in strategic locations to have tools for natural resource management. The primary objective of these areas is to conserve marine biodiversity and ecosystems while promoting the sustainable use of these resources, both permanent and migratory, throughout their life cycles (Lara-Quesada, 2022).

Currently, the country has 27 MPAs protecting 3% of the nation's marine territory. As of 2021, after establishing the Bicentennial Marine Management Area (extension of the Cocos Island National Park and the Montes Submarinos Marine Management Area), the extension of the protected marine territory increased by more than 30%. According to the Biodiversity Law (Decree No. 7778), PAs are classified into six different categories: absolute natural reserve (RNA), national park (PN), national wildlife refuge (RNSV), biological reserve (RB), wetland (H), and marine management area (AMM), These MPAs are administered by the National System of Conservation Areas (SINAC). However, within the category of AMM, marine areas of responsible fishing (RFMA) are under the jurisdiction of the Costa Rican Institute of Fisheries and Aquaculture (INCOPESCA) as the governing body for fisheries, according to Regulation AJDIP/138 of April 4, 2008 (INCOPESCA, 2008).

Importance of marine areas for responsible fishing

Responsible Fishing Marine Areas (RFMAs) arose from the need of fishing groups and associations in the Gulf of Nicoya for the sustainable use of certain fishing grounds where fishing gear and capture methods are regulated for the benefit of coastal communities and the marine resources. The establishment of the first RFMA was initiated by fishermen in Puerto Palito, on Chira Island, for the sustainable use of a fishing ground for the Queen corvina (*Cynoscion albus*), a commercially important species whose catches had been declining over time. As a result, the first RFMA was approved in 2009, as can be seen from INCOPESCA's Board of Directors agreement (AJDIP/315-2009) called "Palito-Montero Marine Responsible Fishing Area", which, according to the Fisheries Management Plan (POP), only allows the use of hand lines (a fishing gear in which a line with one or more hooks is cast and collected by hand) to catch the different species in the area (Lara-Quesada, 2022). Subsequently, other similar initiatives emerged. Currently, there are 13 RFMA: 12 are located on the Pacific coast and one on the Caribbean coast (Barra del Colorado) (Figure 11.1).

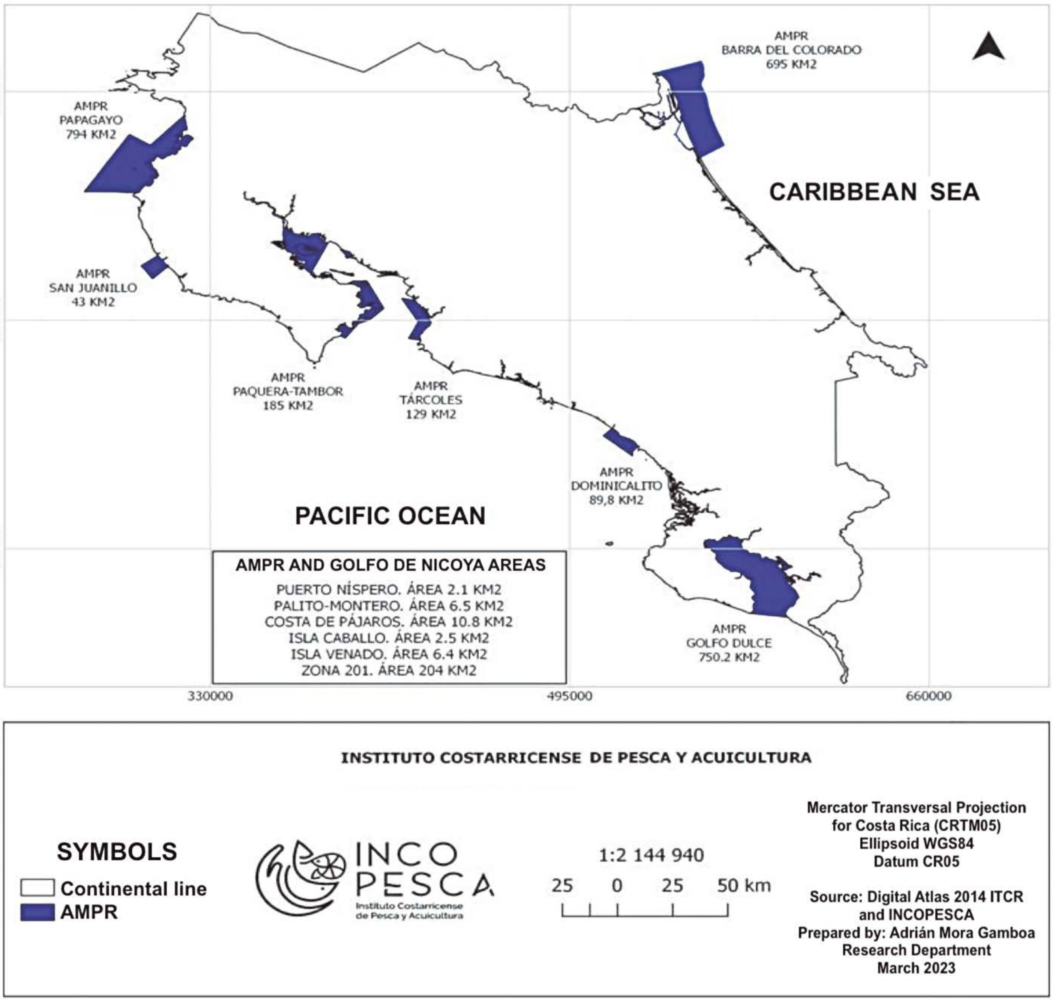

Figure 11.1. Marine Responsible Fishing Areas in Costa Rica.

Source: INCOPESCA, 2023.

Case study of the Paquera–Tambor District RFMA

The experience of fishers from the RFMA (Responsible Fishing Marine Area) Palito-Montero in 2009, along with the information they shared with other fishing communities in the country on various relevant topics—such as improved catches, reduced fishing effort (as fishing grounds are better protected and only certain selective fishing gear is allowed to achieve better and larger catches)—led to increased support from state institutions (such as the National Coast Guard Service, INCOPESCA, the Ministry of Agriculture and Livestock, and the Development Bank, among others), as well as from non-governmental organizations (NGOs) and civil society.

The involvement of allied institutions, organizations, and civilians motivated other coastal communities to develop their own RFMAs. These areas are not for the exclusive use of a community or group, since fishing activity is allowed for both members of the applicant group and any other fishermen or fisherwomen who have a valid fishing license and comply with Fisheries Management Plan regulations (Executive Decree No. 35502-MAG). One of these cases of RFMA replication is that of the Paquera-Tambor District, which was established in 2014 (per agreement AJDIP/099-2014) and extends from Bahia Ballena in Puerto Tambor to Playa Naranjo in the Lepanto district (185 km^2) (Soto-Rojas *et al*., 2018). A particular characteristic of this RFMA is its variety of ecosystems, from mangroves and muddy bottom beaches to rocky reef areas, allowing the development of different economic activities such as fishing, tourism, recreational diving, and scientific tourism, among others. Despite its size (one of the largest RFMAs in Costa Rica), the main users took on a sense of ownership for each sector (Figure 11.2) when establishing and executing the agreed-upon Management Plan.

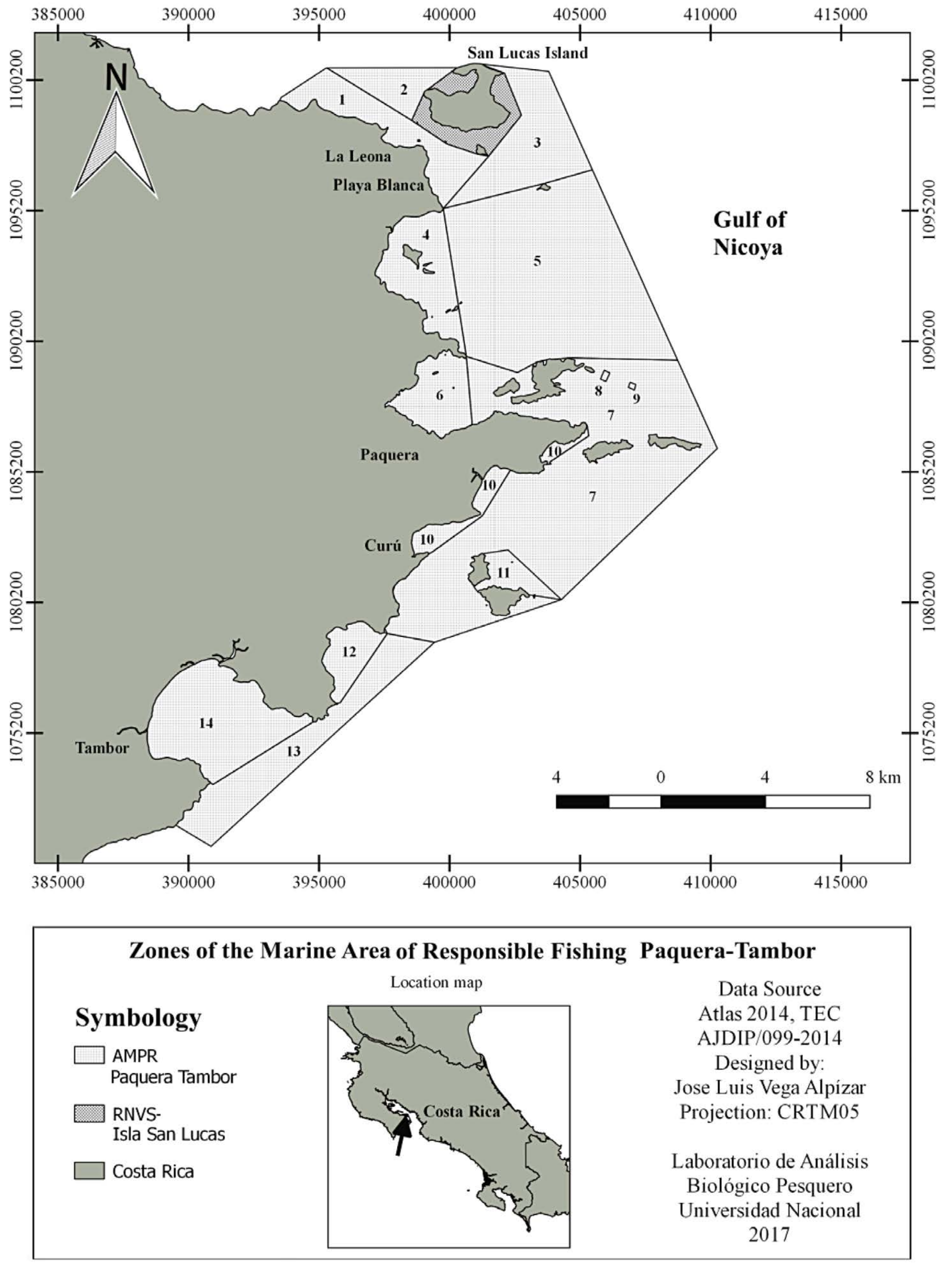

Figure 11.2. Zoning of the Paquera-Tambor District RFMA.

Source: Own elaboration.

Since 2019, the Laboratorio de Análisis Biológico Pesquero (LABIP) of the Marine Biology Station at the Universidad Nacional has actively supported a graduation research project focused on the significance of the RFMA in the Paquera-Tambor District and its contribution to small-scale fisheries. For over twenty years, the LABIP has played a key role in fisheries and resource management in Costa Rica.

Some of LABIP's key contributions to fisheries research include:

The *Sustainable Fisheries Management Project for the Gulf of Nicoya* (2002-2007), conducted in collaboration with the Japan International Co-operation Agency (JICA) and INCOPESCA. The project's objectives were to "develop integrated actions that promote sustainable fishing and maintain the income of artisanal fishers in the Gulf of Nicoya".

Another of the Laboratory's contributions in the field of small-scale fisheries was through the project *Identification and evaluation of habitats as responsible fishing areas in the Central Pacific coast of Costa Rica* (2011-2014), whose main objective was to "propose sustainable management strategies for the creation of responsible fishing areas". Between January 2015 and December 2017, the project: *Contributions for the artisanal and semi-industrial fisheries management of the Gulf of Nicoya* was executed; and its objective was to "contribute towards sustainable management of the Gulf of Nicoya through validation of areas of biological-fishing importance, effectiveness of fishing gear, and genetic identification of small pelagic fish populations to support resources sustainably.

Specifically, in the Paquera-Tambor district area, LABIP carried out the project *Contribution to fisheries management of dorado, queen corvina, and striped corvina in the Paquera-Tambor District Marine Responsible Fishing Area (*between January 2018 and December 2021) with the objective of "Promoting responsible fishing in the Gulf of Nicoya, through the analysis of biological-fishing parameters of these three species".

In 2019, the Laboratory collaborated with responsible fishing by providing support for a study on catches as part of a final graduation project. The study determined biometric parameters (total length of the organism, total weight, gutted weight) of the main targeted species (those species with the highest commercial value, such as snappers: *Lutjanus sp*., corvinas: *Cynoscion sp*., dorado: *Coryphaena hippurus*; among others) and the perception of users in the Puerto Tambor sector (main unloading zone in this RFMA) (Figure 11.3).

Figure 11.3. A) Biometric monitoring; B) sample of dorado (*Coryphaena hippurus*); C) corvina agria (*Micropogonias altipinnis*); and D) spotted rose snapper (*Lutjanus guttatus*) and yellowtail snapper (*L. argentiventris*) caught by artisanal fishermen in the Paquera-Tambor RFMA during the study year.

Source: Lara-Quesada, 2022.

The methodology consisted of monthly visits to the fishery product receiving station at the Tambor Artisanal Fishermen's Association (ASOTAMBOR). Upon arrival at the station, each of the species caught by artisanal fishermen and fisherwomen was recorded by its scientific name, as well as the fishing gear used, fishing grounds, and other relevant details. The catches were then grouped by category or commercial group according to the classification used by INCOPESCA. To gather information on the efficiency of implementing fishery management measures in the Tambor sector, the president of ASOTAMBOR was asked for a list of associated members to conduct a structured interview. This type of interview does not restrict respondents to selecting only the given answer choices (Hernández-Sampieri *et al.*, 2014).

Of the total population registered in the organization (48 associates), 25 individuals were interviewed, meeting the following criteria: 1) member of ASOTAMBOR, 2) direct use of fishery resources in the RFMA, and 3) possession of a fishing permit. The selection followed a purposive sampling approach, guided by the specified characteristics. In this case, representativeness of the overall population was not required; rather, a careful and controlled selection of cases with specific characteristics relevant to the research was carried out (Hernández-Sampieri *et al.*, 2014). Additionally, an analysis of fishery landings was conducted (Figure 11.3), comparing data from five years before and five years after the establishment of the RFMA. This analysis was based on reports from the Fisheries and Aquaculture Information Department of INCOPESCA, referring to the total catch per fishing trip.

Among the most important results of the interview, the following were obtained: 50% of the fishers are aware of the RFMA and reported an increase in their catch production, while 36% perceived that their catches remained the same, and only 14% considered that their catches decreased. In addition, 57% were fishing within the boundaries of the RFMA (specifically in zones 11-12 and 13) (Figure 11.2) and the remaining 43% fished outside the area, as they were dedicated to more pelagic species such as dorado *(Coryphaena hippurus*). Another important aspect is that 73 % of the people interviewed were aware of the regulations established in this RFMA, although only 60 % knew what the POP objectives were. On the other hand, 62% indicated that the marine area had benefited them. Some participants stated: "if it were not for the establishment of the RFMA, we would be worse off economically" (Lara-Quesada, 2022). Among the benefits mentioned, respondents highlighted better prices for their products, easier access to ice, fuel, and other fishing supplies (bait, hooks, fishing gear materials, etc.), as ASOTAMBOR handles the commercialization of these fishery products in Nicoya Peninsula, Puntarenas, and San José (Lara-Quesada, 2022).

All (100%) of the interviewed fishers (25 in total) supported the creation of the RFMA, but 80% considered that they should have more support regarding control and surveillance from the National Coast Guard (SNG) and INCOPESCA. The fishing gear authorized by the POP of the Paquera-Tambor District RFMA include hand lines, *gillnet* and artisanal longline (Figure 11.4). According to the analysis, 89% of the people use longlines, 6% use gillnets and 5% use handlines. Most ASOTAMBOR members (73%) accepted these regulations, which is beneficial for sustainable management in the medium and long term. Another management measure allows ASOTAMBOR members to receive and commercialize only fish that meet the minimum legal catch size (TLPC), as regulated by INCOPESCA. Size analysis of catches was also carried out with respect to the size at first sexual maturity (TPMS); as a result, this management measure is met for the following species: corvina agria (*Micropogonias altipinnis*), barracuda *(Sphyraena ensis*), dorado *(Coryphaena hippurus*), yellowtail snapper *(Lutjanus argentiventris*); while compliance is partial for spotted snapper *(L. guttatus*) (68% of the catches are over the TPMS); however, *Lutjanus peru* (silk snapper) does not meet this measure, with only 24% of catches above TPMS.

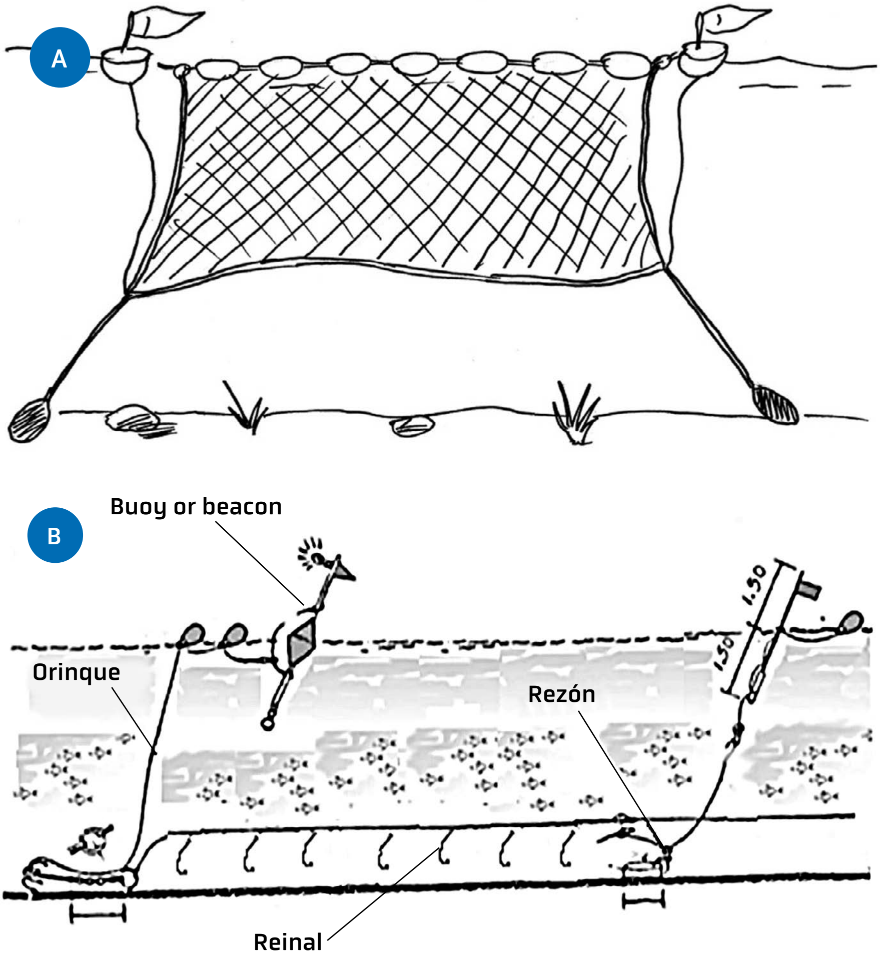

Figure 11.4. Fishing gear permitted in the Paquera-Tambor RFMA, A) gillnet and B) artisanal longline[38].

Source: Laboratorio de Análisis Biológico Pesquero, UNA.

38 In Spanish, *orinque, reinal,* and *rezón* refer to specific components of fishing gear: *orinque* is a rope or line used to secure an anchor or fishing gear to a buoy or another fixed point; *reinal* refers to the main line in certain fishing setups, such as longlining or gillnetting, from which secondary lines or hooks are attached; and *rezón* is a small anchor, often with multiple prongs, used to secure fishing gear or boats in place.

These results demonstrate that the management measures of the RFMA are assumed by the fishers, ensuring the proper use of fishery resources in the medium and long term. According to FAO (1995), the success of fisheries management in a marine area is due to users being involved throughout the process of creating and implementing regulations, as is the case here.

Comparing catch volumes five years before (2009) and five years after (2019) the establishment of this RFMA (2014), a significant increase was observed, rising from approximately 44,300 kg to 203,600 kg in 2019 (Figure 11.5). This increase in catches may be due not only to regulations established by the RFMA, but also to better data collection on behalf of INCOPESCA; a situation that is not occurring in other RFMAs in the Gulf of Nicoya. Another possible cause for this increase could be changes in some fishing techniques and methods, which are more efficient. In addition, most of the people interviewed agree that the elimination of shrimp trawling in the RFMA Paquera-Tambor District, carried out in zones 7 and 13 (fishing grounds known as "El Barreal", Figure 11.2), favors the increase in biomass of the populations; therefore, providing greater catches for the artisanal fleet.

In addition, fishing exclusion zones were established in this RFMA (zones 2-6, part of 7 and 10, see Figure 11.2), which together with the Cabo Blanco Marine Management Area (bordering this RFMA), are sites where reproduction, breeding and recruitment are protected. This is reflected in the catches and the economy of Puerto Tambor fishers, coinciding with FAO (2007) and Executive Decree No. 35502-MAG, which states that the role of MPAs in artisanal and small-scale fisheries, along with regulations on fishing gear, quotas and seasonality, can generate such positive effects for coastal or riverine communities (Hilborn *et al.*, 2006; Russ *et al.*, 2004).

RFMAs play a key role in meeting the UN Sustainable Development Goals, particularly target14.4, which seeks to regulate fisheries exploitation, stop overfishing, and restore wild stocks to sustainable levels in the shortest possible time, through the improvement of Maximum Sustainable Yield (FAO, 2018).

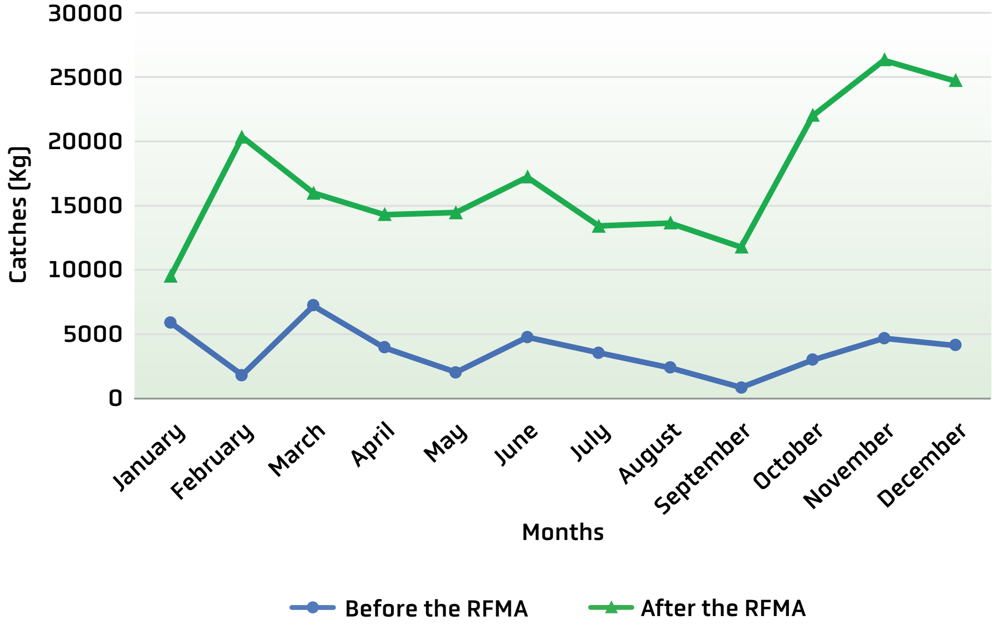

Figure 11.5. Discharge volumes in Puerto Tambor; before (2009) and after (2019) the establishment of the RFMA.

Source: Lara-Quesada, 2022.

Conclusions

- The fishermen of the Tambor Association believe their catches have increased since the establishment of the RFMA Paquera-Tambor in 2014.
- There is a strong sense of ownership among users regarding the RFMA, due to effective information sharing by ASOTAMBOR.
- The majority of fishermen (57%) use fishing grounds within the RFMA's boundaries.
- Among the most commonly caught species, both inside and outside the RFMA, are spotted snapper, mahi-mahi, and weakfish.

- The RFMA Paquera-Tambor hosts a large number of commercially valuable species, with 31 different species identified. These species are distributed throughout the year, helping to ease fishing pressure on highly demanded species like snapper and weakfish.
- Significant differences in catch volumes are mainly due to regulations imposed by the fishers themselves within this RFMA.

Recommendations

- There should be better coordination between state institutions to provide support in resource monitoring and enforcement.
- Fishery resource assessments should be conducted at least every five years to maintain or adjust management measures as needed.
- Communication between the Paquera-Tambor RFMA and the Cabo Blanco AMM should be strengthened, as their boundaries overlap in areas where various fishing fleets operate, including sport, tourist, and commercial (both medium and small-scale) fisheries.

Lessons learned

- An integrated effort between academia and small-scale fishing communities requires knowledge and analysis of the culture, customs, and fishing techniques. This ensures accurate information through the implementation of citizen science in future research.
- All efforts in coastal marine resource management require that decisions be made through consensus among users, the state, academia, and the supply chain. Moreover, information regarding management conditions must be shared transparently.

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Coastal biological monitoring in Costa Rica: a case study on harmful algae blooms

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Costa Rica integrated Sustainable Development Goals (SDGs) in its social, economic and environmental planning as part of its 2030 Agenda. The country recognizes oceans as one of the greatest challenges for development and values international cooperation as a key strategy to strengthen its technical-scientific capacities.

For example, the National Development and Public Investment Plan 2023-2026 highlights the need to address environmental deterioration caused by demand for resources, pollution, and climate change. In order to move towards sustainable development, adaptation and environmental recovery measures need to be implemented. The Plan contemplates actions to increase marine protected areas and promote economic reactivation in coastal areas, emphasizing sustainable fisheries and aquaculture production for the benefit of coastal communities. It also seeks to promote research and development through training and knowledge transfer. Support for scientific research and strengthening of vulnerable coastal communities through partnerships for conservation and adaptation to climate change are also included in the plan.

In this context, coastal biological monitoring, with citizen participation and inter-institutional alliances supported by international cooperation, becomes a fundamental tool for generating scientific evidence to guide decision-making in favor of SDG 14, *Underwater Life*. In particular, for goals 14.1 "Prevent and reduce pollution", 14.2 "Sustainably manage and protect marine and coastal ecosystems" and 14.a "Increase scientific knowledge, develop research capacity and transfer marine technology".

Biological monitoring is essential for managing ecosystems, in order to evaluate their health at different levels (species, populations, communities) and to detect changes over time. This makes it possible to identify and address problems such as biodiversity loss, the effects of climate change, pollution, and resource overexploitation. Additionally, this type of monitoring determines the effectiveness of conservation actions in marine protected areas and evaluates the environmental impact of human activities to mitigate their effects.

Long-term monitoring programs will allow the identification of determining factors for the stability of ecosystems or those that produce significant disturbances in their structure and function. This should be considered for management, governance and development of public policies for sustainable use of natural resources. Therefore, the State should be actively involved in the development and implementation of biological monitoring, through continuous funding and the integration of various institutions. Thus, Costa Rica has the opportunity to be a regional leader in sustainable ocean development, integrating participatory coastal biological monitoring for the generation of scientific evidence to implement policies aimed at the sustainable management of marine-coastal resources.

Since its foundation, the Escuela de Ciencias Biológicas (ECB) of the Universidad Nacional considered biological monitoring as a key aspect for the development of the country's marine-coastal sciences. It initially embraced topics such as fisheries, aquaculture, algal blooms, and mangroves. Over time, it has diversified its activities in other areas, such as emerging contaminants, rocky reefs, water quality, microbial communities, among others. This has allowed greater understanding of the marine environment and articulated efforts in conjunction with other governmental institutions, coastal communities and international cooperation, to improve management of marine-coastal ecosystems and resources.

Several monitoring actions have surpassed science and academe, generating key inputs for decision-making in national public policy. For example, based on research projects on mangrove and rocky reef ecosystems, led by academics from the ECB, the National System of Conservation Areas (SINAC) consolidated the National Ecological Monitoring Protocols for Rocky Reefs and Mangroves. These are monitoring tools based on indicators that allow authorities to identify changes over time and, thus, implement management and conservation measures (SINAC-UNA, 2020; SINAC-UNA, 2021).

According to the United Nations Environment Program, 2023, the loss of 3.4% of global mangrove cover in recent decades, attributed to human activities such as agricultural expansion, urbanization, and climate change, has generated significant ecological and socioeconomic effects for coastal communities. In response, Costa Rica adopted various conservation measures, including the ratification of the Ramsar Convention in 1991 and the implementation of the National Wetlands Policy in 2017, prompting the creation of the first National Blue Carbon Strategy worldwide. This strategy seeks integration of actions for management, conservation, restoration, and rehabilitation of blue carbon ecosystems. Another example of the ECB's scientific leadership is the study of Harmful Algal Blooms (HAB) at the Laboratorio de Fitoplancton Marino (LABFITMAR), whose incidence led to the creation of an Inter-institutional Commission to mitigate intoxications caused by consumption of seafood products contaminated by phytoplankton toxins.

Over time, biological monitoring carried out by ECB staff has been strengthened by coastal community participation, achieving results together with people living in the areas. Their participation and commitment are fundamental in order to achieve effective management of marine ecosystems, since awareness of the importance of marine biodiversity is increased together with a sense of responsibility for the environment. In addition, local knowledge complements scientific information. Conservation and the sustainable use of marine resources are strengthened, which benefits both communities and ecosystems. Likewise, biological monitoring has promoted international cooperation and the articulation of efforts with other institutions.

The following is a case study on coastal biological monitoring of HABs that was conducted by ECB staff, other governmental institutions and coastal communities.

Case Study: Harmful Algae Bloom Monitoring in Costa Rica: Lessons and Challenges in the Era of Information

Researchers Roxana Víquez and Emilia Calvo created and have been supporting the LABFITMAR at the ECB since the 1980s. It was during that decade when HABs were first documented along the Pacific coast of Costa Rica and were associated with the harmful dinoflagellate *Margalefidinium polykrikoides*. Although this species is non-toxic, it has caused economic losses due to mortality of marine organisms (fish, shrimp, among others) and has affected tourism. However, *M. polykrikoides* is not the only HAB producing species in the country, nor is it considered one of the most dangerous in terms of human health. *Pyrodinium bahamense* and *Gymnodinium catenatum* have also been linked to HAB events and are known for producing paralytic toxins that can cause poisoning and even death in people who consume bivalve mollusks that have accumulated these toxins in their tissues.

When multiple cases of people affected by toxins produced by phytoplankton occur, it is considered an outbreak. In Costa Rica, the first outbreaks of phytoplankton toxin poisoning were documented in 1989 and between 1999-2002, with 14 and 70 people affected, respectively, due to the consumption of mollusks containing toxins produced by *Pyrodinium bahamense* (Mata *et al.,* 1990; Vargas-Montero & Freer, 2002). The analysis of these cases raised awareness on the impact of HABs on public health. Thus, Costa Rica received a first lesson by identifying the need to establish continuous monitoring to prevent new outbreaks.

Currently, monitoring is coordinated by the Commission for Epidemiological Surveillance of Red Tide, including government institutions, universities and fishing authorities that carry out toxicological analyses on bivalve mollusks and monitor the concentration of toxic microalgae. Local oyster producers and wild mollusk extractors also participate. This inclusion of the productive sector in national HAB management processes is a key point in establishing sanitary restrictions, as mollusk harvesters recognize the importance of ensuring the safety of the seafood they collect and sell.

By involving key stakeholders in epidemiological surveillance protocols, productive, academic, and health related activities are interconnected. This fosters awareness of the impact of natural phenomena and marine resource management on society and highlights the second lesson learned in Costa Rica: citizen participation in resource management activities.

As part of the continuous monitoring established in Costa Rica, seawater and bivalve mollusk meat samples are collected and analyzed by LABFITMAR and the National Animal Health Service (SENASA). The HAB monitoring network on the Pacific coast of Costa Rica is shown in Figure 12.1, which details sampling locations carried out by both institutions and local communities.

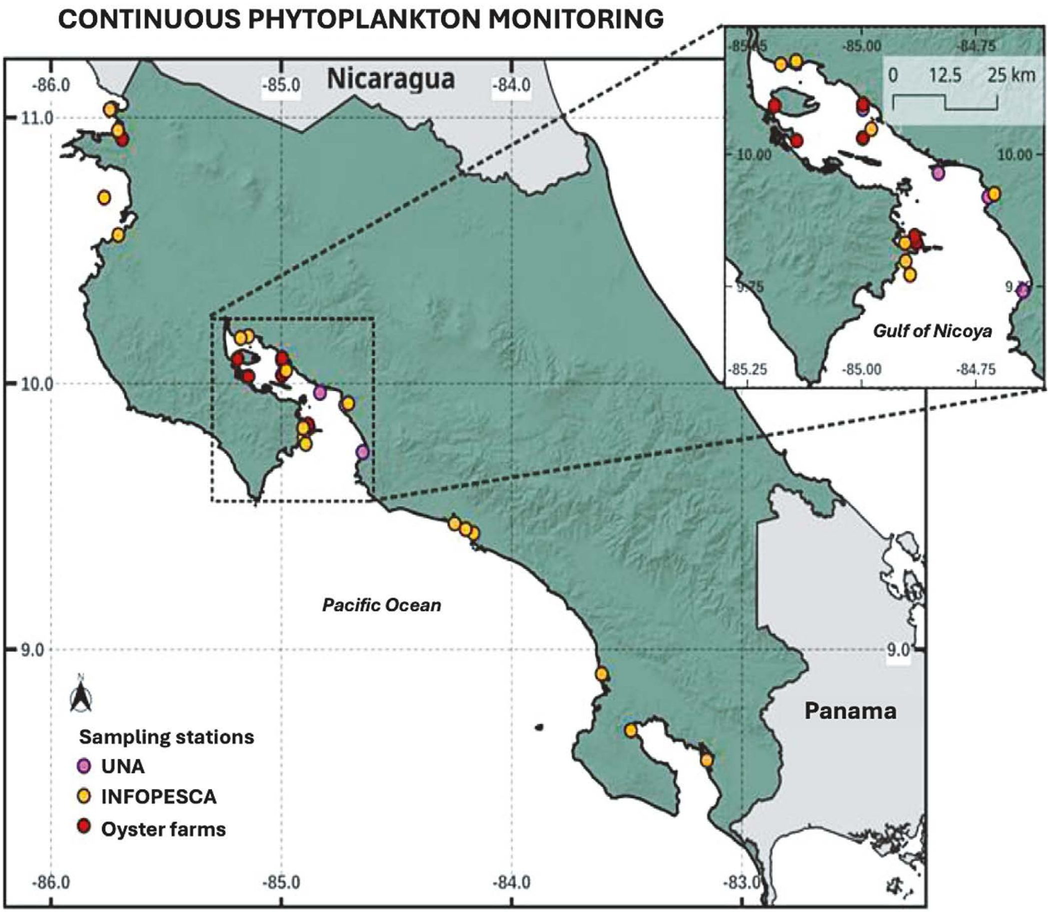

Figure 12.1. Network of sampling stations of the Epidemiological Surveillance Commission for Red Tide in Costa Rica. Water and seafood samples are collected or contributed by the Costa Rican Institute of Fisheries and Aquaculture (orange dots), LABFITMAR (pink dots) and local oyster farms (red dots). The inset map is a detail of the Gulf of Nicoya where LABFITMAR has periodically sampled every two weeks since 2003.

Source: Own elaboration.

In this monitoring network, LABFITMAR collects, on a biweekly basis, surface seawater samples at four stations in the Gulf of Nicoya, which has allowed construction of a robust database dating from 2003.

This monitoring is useful to understand the dynamics of HABs and has revealed, for example, the rise of HABs during the cold phase of the El Niño Southern Oscillation (Calvo *et al.*, 2014).

On the other hand, the historical record of HABs maintained by LABFITMAR for more than twenty years will allow the study of long-term trends that could be associated with human activities such as pollution and climate change. Thus, a third lesson that Costa Rican institutions have understood is the importance of maintaining and financing regular long-term monitoring, which in the case of LABFITMAR, represents 21 years of continuous monitoring.

Another contribution of monitoring is the study of toxin-producing dinoflagellate resistance phases, known as resistance cysts (Figure 12.2), which can serve as the "seedbed" for algal blooms. From this study, it was possible to identify seedbed areas of potentially toxic dinoflagellates in the Gulf of Nicoya. This information is essential for establishing preventive measures against potential HABs, especially those involving toxin-producing species that cause paralytic effects, as well as for the development of mariculture projects, particularly the cultivation of bivalve mollusks.

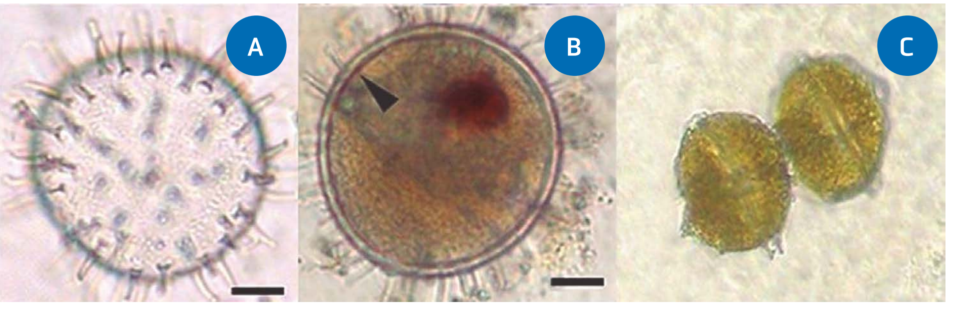

Figure 12.2. *Resistance cysts and vegetative cells of Pyrodinium bahamense:* A) A hemispherical-shaped cyst with spine-like processes on the outer layer of the cell wall; B) A cyst containing cellular material, showing its red body and the inner layer of the cell wall (endophragm [indicated by the arrow]; C) A vegetative cell forming a chain of two cells. Scale bar = 10 µm.

Source: Quirós, 2020.

One of the key conclusions of this study was that sites located in the outer and middle parts of the Gulf of Nicoya (Herradura, Punta Leona, Tárcoles, Bahía Caldera, Cedros Island, and San Lucas Island) are not considered suitable for the development of productive mariculture projects, due to the presence of dinoflagellate *P. bahamense* seedlings, which produce paralytic toxins and form HABs (Figure 12.3).

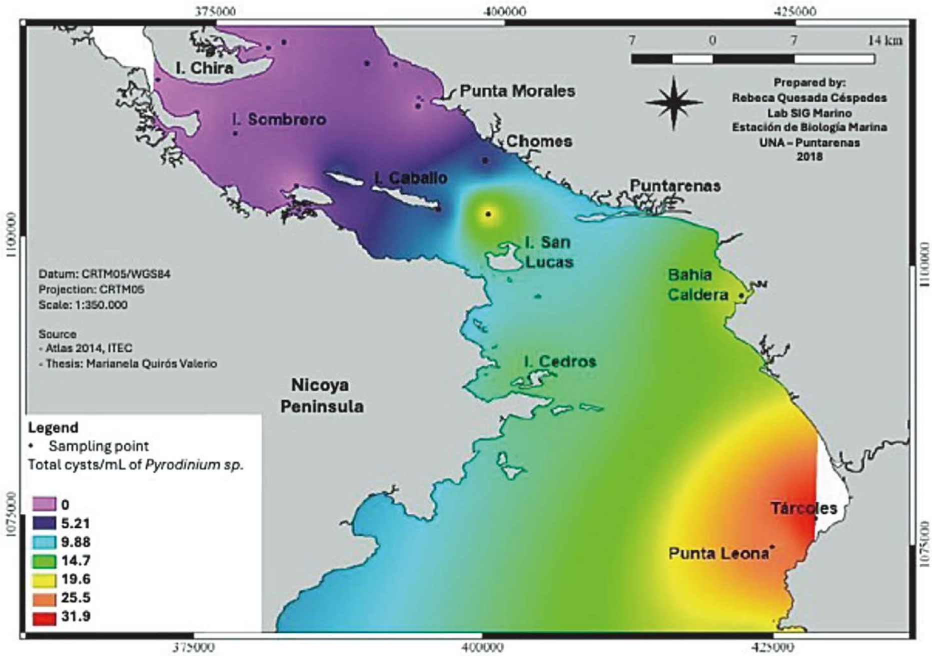

Figure 12.3. Spatial distribution of the concentration of viable resistance cysts of *Pyrodinium bahamense*, during the period from April 2013 to April 2014, Gulf of Nicoya, Puntarenas, Costa Rica.

Source: Quirós, 2020.

HAB events do not depend solely on the presence or absence of cysts but are determined by environmental conditions and dispersal processes. Cysts can germinate in the area identified as a seedbed and, later, be carried to another location by marine currents (Matsuoka & Fukuyo, 2000).

Final considerations

Throughout the research on HABs in Costa Rica, three key lessons have been identified:

– It is essential to have an interinstitutional commission to monitor HABs and make decisions to protect human health and marine-coastal ecosystems.

– The participation of local communities in sampling is crucial, as the health and economic sustainability of their inhabitants are directly affected by HAB dynamics.

– Maintaining and funding continuous monitoring is fundamental to understanding HAB dynamics, which can be influenced by both natural phenomena and human activities.

As a result of these lessons, Costa Rica has implemented a surveillance system since 2014 to prevent cases of poisoning from consuming bivalve mollusks. This system includes continuous training for the mollusk sector, government, and health institutions, as well as the scientific and technical infrastructure provided by the ECB. This initiative has raised awareness about the prohibition of marketing and consuming bivalve mollusks during HAB events, ensuring the safety of marine products.

However, there are still areas for improvement, such as the creation of digital platforms and the use of social media to inform the public about HABs, as well as making data available to public repositories for the scientific community. Additionally, the integration of new technologies, such as satellite measurements and artificial intelligence techniques, is also needed to optimize monitoring and analysis of HABs. The main challenge remains the lack of funding for equipment and specialized personnel, which limits research and response capabilities to these phenomena.

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Eastern Tropical Pacific Thermal Dome: Importance and Challenges for the Blue Economy

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The Eastern Tropical Pacific Thermal Dome (ETPTD) is a unique oceanic-atmospheric phenomenon in the Americas. It is located off the Pacific coast of Central America and is characterized by the upwelling of large masses of deep, cold, nutrient-rich water to the surface. This process increases biological productivity and biodiversity in the region (Ross *et al.*, 2019; Jiménez, 2016). These characteristics make the dome a high-value public good due to the ecosystem services it provides, benefiting economic activities such as fishing and marine tourism (García and Segura, 2024). These benefits are utilized both by Central American countries and nations beyond the region (Jiménez, 2016).

Another key feature of the dome is its location in the high seas, beyond national jurisdiction, which poses a challenge for regional and global governance. In response, in 2022, the MarViva Foundation, together with the Sargasso Sea Commission, the University of Western Brittany, and the French Office for Biodiversity (OFB) established the SARGADOM project. This initiative aims to contribute to the creation of hybrid governance models for the protection and management of resources in the high seas (García and Segura, 2024). One of the key instruments is the Treaty on the Conservation and Sustainable Use of Biodiversity Beyond Areas of National Jurisdiction (BBNJ), approved by the United Nations in June 2023 (United Nations, 2023). Its implementation requires facilitation across different countries. In addition to the lack of regulation, another major obstacle faced by maritime zones like the ETPTD is the scarcity of up to date quantitative and qualitative information, as well as an understanding of its socioeconomic value to guide sustainable use (García and Segura, 2024). Ross *et al.* (2019) identified some studies highlighting the economic contribution of activities related to the dome. For example, the shark-watching tourism industry in Costa Rica generated an estimated $236,000 in 2006, while sport fishing contributed $599 million in 2008. However, these figures are broad and outdated.

In 2023, a research team from the Centro Internacional de Política Económica (CINPE) at the Universidad Nacional, in collaboration with the MarViva Foundation, developed a study to assess the role of the ETPTD. In addition to its inherent value for marine biodiversity, it also holds significant value from an economic perspective. Through data collection and analysis, the study focused on quantifying the economic contributions of commercial and sport fishing, as well as marine wildlife tourism, in five countries in the region during the 2017-2022 period. The objective of this chapter is to present the main findings and research methodology, as well as to propose economic policy recommendations for the sustainable use of this unique area.

The location of this oceanographic phenomenon is influenced by trade winds, the interaction of ocean currents with the Intertropical Convergence Zone, and climatic phenomena such as El Niño Southern Oscillation (ENSO). These factors cause the dome's extent to expand and contract seasonally, covering thousands of square kilometers throughout the year. According to research conducted over the last fifty years, variations in its size can range between 200 and 1,000 km, and its total area fluctuates between 800 and 1,000,000 km^2 (Ross *et al.*, 2019).

Monthly oscillations in the diameter of the ETPTD reach their maximum expansion in November and December. In October, approximately 85% of its extension is located in international waters, while between March and April, it is predominantly located in the Exclusive Economic Zones (EEZ) of Costa Rica, Nicaragua, and southern Mexico (Figure 13.1). These dynamics pose a challenge for geographically defining the ETPTD. However, thanks to research conducted by the MarViva Foundation, its boundaries have been more precisely determined using persistence lines[48]. The core of the dome can be located at coordinates 9.56°N and 92.58°W, with its outmost limits approximately 20 miles (32 km) off the coast.

48 For this purpose, this considers value of the thermocline at 20 degrees and measured at a depth of 35 meters, as well as the determination of the degree of constancy of these values over 30 years (1980-2009).

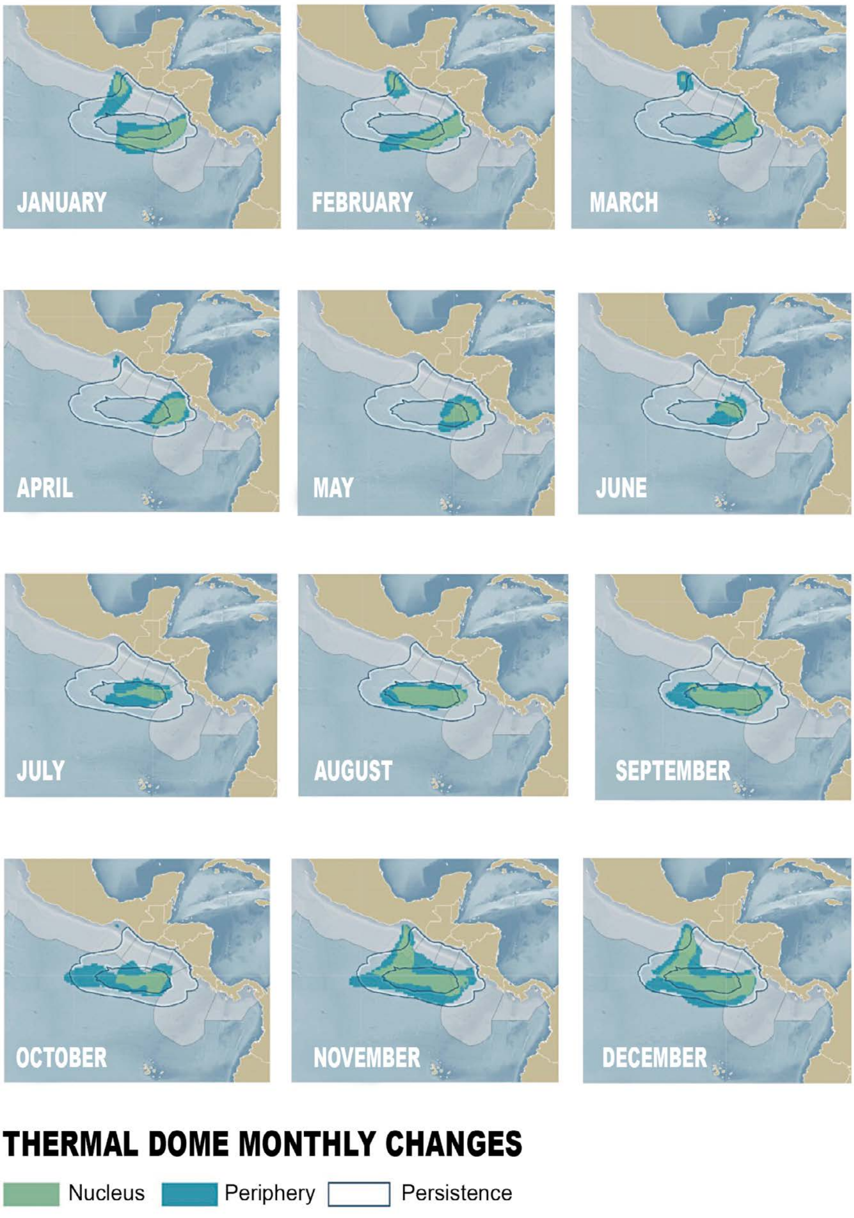

Figure 13.1. Monthly displacement of the ETPTD.

Source: CINPE-UNA with data from Duke University, 2023.

The delimitation includes portions of the maritime jurisdiction zones of southern Mexico, Guatemala, El Salvador, Nicaragua, and Costa Rica, covering a total of five countries of interest. Off the coasts of these countries, the phenomenon of the dome facilitates the upwelling of nutrient-rich waters and creates an environment conducive to a wide diversity of marine species.

Data compiled in the *Thermal Dome Atlas of Costa Rica* reveals that about 70 species groups inhabit or frequent the ETPTD (Ross *et al.*, 2019), ranging from marine zooplankton to blue whales (Table 13.1). Additionally. the blue whale (*Balaenoptera musculus*), sailfish *(Istiophorus platypterus*), silky shark (*Carcharhinus falciformis*), and Kemp's ridley turtle *(Lepidochelys kempii*), which inhabit the dome, are recognized as flagship species due to their crucial role in the ecology of this habitat, as well as for their notable migration or mobility behaviors.

Once the study area was defined and the natural importance of the dome was recognized, a research methodology was developed to analyze the relationship between marine abundance and diversity, as well as their relationship with certain productive activities. To achieve this, key species groups were selected for their relevance in fishery and tourism activities, with the objective of subsequently assessing the economic impact generated by their interactions in this region.

The previously mentioned flagship species hold tourist value, particularly for activities such as whale watching, including the humpback whale (*Megaptera novaeangliae*), thresher shark (*Alopias superciliosus*), blue shark (*Prionace glauca*) and hammerhead shark *(Sphyrna lewini*), pelagic rays *(Pteroplatytrygon violacea*), and leatherback *(Dermochelys coriacea*) and olive ridley *(Lepidochelys olivacea*) sea turtles. Additionally, some of the species' groups in the study area are recognized for their considerable commercial value in the fishing industry, highlighting their contribution in terms of catch, sales, and exports. Among them, the yellowfin tuna (*Thunnus albacares*) stands out, as it frequents the dome as one of its breeding areas, making it one of the main fishing zones globally (Jiménez, 2016).

Other commercially important species include the common dorado (*Coryphaena Hyppurus*), marlin (Istiophoridae), and swordfish (*Xiphias Gladius*), which are captured using fishing methods such as purse seines and longlines practiced in the dome area. In summary, these species groups were selected to quantify the economic contributions of the ETPTD (marked by an asterisk in Table 13.1).

Table 13.1: Species groups inhabiting or frequenting the ETPTD

Common name	Scientific name
Blue needle	*Makaira nigricans*
Luminous anchovy	*Vinciguerria lucetia*
Yellowfin tuna*	*Thunnus albacares**
Bigeye tuna*	*Thunnus obesus**
Blue whale*	*Balaenoptera musculus**
Black kite*	*Euthynnus lineatus**
Lead or hard drumstick	*Epinephelus niphobles*
Giant squid	*Dosidicus gigas*
Tropical Calderon	*Globicephala macrorhynchus*
Krill Shrimp	*Euphasia eximia*
Red mysid shrimp	*Gnathophausia ingens*
School sharks	Carcharhinidae
Common dolphin*	*Delphinus delphis**
Spinner dolphin	*Stenella longirostris*
Striped dolphin	*Stenella coeruleoalba*
Spotted dolphin	*Stenella attenuata*
Bottlenose dolphin	*Tursiops truncatus*
Derivative ojon	*Cubiceps pauciradiatus*
Common mahi mahi*	*Coryphaena hippurus**

Common name	Scientific name
Dwarf gilt	*Coryphanea equisells*
Dwarf scorpion	*Scorpaenodes xyrisa*
Euphausiaceans	*Euphauslides*
Arrow worm	*Quetognatos*
Toothed sole	*Cyclopsetta querna*
Elongated lantern	*Lampanyctus parvicauda*
Diogenes lantern	*Diogenichthys laternataus*
Luminous stippling	*Vinciguerria lucetia*
Alfredi blanket	*Mobula alfredi*
Horned blanket	*Mobula tarapacana*
Thorn blanket	*Mobula japanica*
Monk's blanket	*Mobula munkiana*
Folded blanket	*Mobula thurstoni*
Giant blanket	*Mobula birostris*
Manta ray	*Mobula alfredi*
Marlin*	Istiophoridae*
Black marlin	*Istiompax indica*
Striped marlin	*Kajikia audax*
Orca	*Orcinus orca*
Rainbow fish	*Melonis affinis*
Swordfish*	*Xiphias gladius**
Hammerfish	Sphyrnidae
Sailfish*	*Istiophorus platypterus**

Common name	Scientific name
Pelagic ray	*Pteroplatytrygon violacea*
Striped	*Katsuwonus pelamis*
Spanish sardine	*Sardinops sagax*
Miss Stone	*Halichoeres semicinctus*
Blue shark*	*Prionace glauca**
Whale shark	*Rhincodon typus*
Hammerhead shark*	*Sphyrna lewini**
Smooth hammerhead shark	*Sphyrna zygaena*
Oceanic whitetip shark	*Carcharhinus longimanus*
Silky shark*	*Carcharhinus falciformis**
Thresher shark	*Alopias superciliosus*
Leatherback turtle	*Dermochelys coriacea*
Olive ridley turtle*	*Lepidochelys olivacea**
Green turtle*	*Chelonia mydas**
Bearded flyer	*Exocoetus monocirrhus,*
-	*Myctophum orientales*
-	*E. lamelligera*
-	*Eucalanus inermis*
-	*Ptecorys minythorax*
-	*Eucalunus subtenuis*
-	*S. subtenuls*
-	*Uvigerina hispida*

Common name	Scientific name
-	*Bathophilus spp*
-	*Cibicidoides mundulus*
-	*Bathophilus filifer*
Marine zooplankton	-

Source: CINPE-UNA with data from Ross *et al.*, 2019.

To quantify productive activities and economic impact of the dome, various sources of information were used, each with certain advantages and limitations. In the case of fishing activity, geospatial data delimited to the area of the ETPTD were collected from Global Fishing Watch (GFW), which provides information on fishing effort measured in hours, both for purse-seine and longline vessels[49], classified by flag. These data are obtained through AIS (Automatic Identification System) and VMS (Vessel Monitoring System) tracking systems, which record real-time location, movements, and hours in each area, although without specifying the type of catch. Additionally, information from the Inter-American Tuna Organization (IATTC) on tuna caught by affiliated purse seiners and by flag was considered.[50]

Each data set was processed using specific techniques. In the case of data provided by IATTC, the tonnage of tuna caught in the dome during the study period was multiplied by the average market price for each year. This price was estimated from data collected from institutions of the five countries selected for the study. On the other hand, analysis of data provided by GFW focused on purse seine vessels, for which an average daily capacity of 300 tons was determined, based on the range of their storage capacity according to the International Commission for the Conservation

49 Longline is a fishing is a technique that involves using a long, floating main line equipped with multiple hooks; while purse seine vessels use a fishing method that involves encircling a portion of water with a circular net to catch fish inside it.

50 CIAT information is limited to tuna fishing and only includes member countries, thus excluding Guatemala and El Salvador.

of Atlantic Tunas (ICCAT, 2008)[51]. Using this average capacity and hourly records, converted to days, an estimate of the catch tonnage during the study period was calculated. Finally, average regional market prices were applied for each year. Table 13.2 compares results from both sources, only for purse-seine fishing.

Table 13.2. Value of commercial fishing in the ETPTD by purse-seine vessels from the countries under study, according to GFW and CIAT data.

Year	GFW Data		CIAT Data	
	Tonnage	Value (dollars)	Tonnage	Value (dollars)
2017	55 200	118 790 400	15 548	33 459 296
2018	76 500	165 087 000	17 035	36 761 530
2019	32 700	59 546 700	15 222	27 719 262
2020	47 700	77 989 500	9 948	16 264 980
2021	28 500	45 913 500	13 376	21 548 736
2022	20 100	32 381 100	7 410	11 937 510
Total	**260 700**	**499 708 200**	**78 539**	**147 691 314**

Source: CINPE-UNA with data from GFW, 2023 and CIAT, 2023.

In the case of sport fishing and species sighting, there is no georeferenced information available; therefore, the estimation of the economic contribution of the dome to these activities required additional methodological assumptions. Regarding sport fishing, to establish a connection between the income generated by this activity and the ETPTD, results of Chaminade and Hernández (2020) on sport fishing catches in the marine area of Corcovado National Park, on the Pacific coast of Costa Rica, were considered. The results show that four of the eight main species groups

51 Only catch tonnage of the purse seine fishery could be estimated, since there is no data available on average capacity of the longline fleet; the fishing analysis is therefore partial.

caught in sport fishing correspond to groups that inhabit or frequent the dome (tuna, dorado, sailfish, and marlin).

This information suggests a significant portion of the catches is possible due to the presence of the ETPTD; however, for a more accurate analysis, information on the main sport fishing catch tonnage for each species type is needed. A 50% reduction was applied to the total estimated value of sport fishing in the study. Within the study area, only El Salvador, Guatemala, and Costa Rica record data on sport fishing tourism, although not for every year.[52] This limits the estimation of indirect expenditures, leading to an underestimation.

Different economic flows directly derived from sport fishing were identified. On one hand, the income the state receives through the issuance of permits, licenses, cards, as well as from organizing tournaments related to this activity in the selected countries. On the other hand, the expenses incurred by tourists engaging in this activity, such as transportation, lodging, food, and those related to crew and boat maintenance.[53] These expenditures are converted into income for those who receive them (Table 13.3). The information used for this analysis came from national sport fishing and tourism institutions of each country, as well as a study on the profile of tourists attracted to sport fishing by Villalobos (2021).

52 In sport fishing, there are significant gaps, because in some countries' tourism institutions do not record information or do not do so for all periods. In addition, methodologies are not comparable, which complicates analysis.

53 Only Costa Rica has a complete record of the number of boats used to transport sport fishing tourists. This means that in the other countries, calculation of indirect income is incomplete and an underestimate.

Table 13.3. Value of activities related to sport fishing in the countries under study

Year	Value of State revenues from permits or licenses (dollars)	Value of income from miscellaneous tourist expenses (dollars)	Total
2017	505 893	432 644 155	433 150 048
2018	523 049	439 757 764	440 280 813
2019	417 175	455 348 200	455 765 375
2020	297 623	130 152	427 775
2021	286 005	230 840 278	231 126 283
2022	14 524	356 716 686	356 731 210
Total	**2 044 269**	**1 915 437 235**	**1 917 481 504**

Source: Prepared by Cinpe-UNA with data from CONAPESCA, 2022; INCOPESCA, 2023; INPESCA, 2021; MAGA, 2023; CORSATUR, 2023 and FECOP, 2018 & 2019.

In the case of wildlife watching tourism, the main obstacle was the lack of statistics and secondary information in the countries of the region. For this reason, primary information was collected through interviews.[54] In 2023, the research team interviewed staff involved in companies offering whale watching tours on the Pacific coast of the five countries under study (Table 13.4). Based on this information, the revenue was estimated for the total number of identified companies offering this service in each country

54 Interviews with sighting service providers were conducted online or by telephone, except in Costa Rica, where they were conducted in person.

Table 13.4. Revenue from whale watching in the countries under study year 2023

Country	Average annual amount per company (dollars)	Number of companies	Annual amount per country (dollars)
Costa Rica	632 394	15	9 485 910
Mexico	679 680	20	13 593 600
El Salvador	77 168	6	463 008
Nicaragua	279 300	3	837 900
Guatemala	21 460	6	128 760
Total	-	**50**	**24 509 178**

Source: CINPE-UNA with data from interviews with whale watching tour operators, 2023.

The analysis of the results by activity reveals significant information regarding their ability to support local and regional economies, which are essential for the generation of employment and the well-being of communities in the region, as well as in other countries. Expenditures by sport fishing and whale watching tourists are revenues that not only benefit the businesses directly involved, but also drive development of other local industries, such as hotels and commerce, which are important in coastal areas of the countries.

Regarding commercial fishing, benefits provided by the ETPTD go beyond regional boundaries. GFW data (Table 13.5) show that 76% of the fishing effort in the dome corresponds to longline vessels (4,528 days) and 24% to purse seiners (1,405 days). In the case of longline vessels, less than 1% of the total fishing effort comes from the countries analyzed; the rest originates from countries outside the region, primarily Taiwan. This highlights the need to implement policies and strategies that promote sustainability and equitable utilization at the international level. In contrast, 62% of the purse seine fishing in the dome area is attributed to vessels from the countries under study.

Table 13.5. Fishing effort in days, by fishing gear and flag, 2017-2022.

Country	Fishing gear			
	Purse Seine		Longline	
	Total days	Percentage	Total days	Percentage
Bermuda	112	8,0	0	0,0
Fiji	0	0,0	739	16,3
Mexico	576	41,0	0	0,0
Nicaragua	295	21,0	0	0,0
Panama	169	12,0	192	4,2
Taiwan	0	0,0	3429	75,7
Venezuela	239	17,0	0	0,0
Others[a]	14	1,0	169	3,7
Total	**1 405**	**100,0**	**4 529**	**100,0**

[a] Includes: Colombia, China, Ecuador, Spain, El Salvador, Japan and Vanatu.
Source: CINPE-UNA with data from GFW, 2023.

This comprehensive approach to research allows understanding and concluding that at least 11 groups of species inhabiting or visiting the ETPTD support vital economic activities such as commercial and sport fishing, as well as sight-seeing tourism. Their preservation contributes to long-term sustainability of these and similar activities in the region.

The economic contributions of these activities, with updated data, range from US$24.5 million per year for whale watching (Table 13.4), to more than US$200 million in annual expenditures related to sport fishing (Table 13.3, applying a 50% adjustment for catches of species groups that inhabit or visit the ETPTD). The estimated contribution from commercial fishing varies depending on the scenarios summarized in Table 13.2, with GFW data ranging from US$32 million to over US$160 million, representing an average of nearly 29% of the fishing GDP value of Mexico and Central American countries.

However, it is necessary to implement regulatory and monitoring measures for the different activities in order to have a more accurate assessment of the blue economy in this territory. Some recommendations in this respect are the establishment of protected areas focused on fishing, considering their carrying capacity, as well as the regulation of navigation routes and sustainable fishing gear. Other essential measures include the implementation of national infrastructures for the sustainable development of the fishing and tourism sectors, promoting the use of technology to collect data, standardization in the recording of statistics, and safeguarding national interests of small countries in the broad Pacific Ocean region.

All these measures in favor of the blue economy are essential actions that must be adopted to ensure sustainability of this invaluable ecosystem. Finally, in accordance with the promotion of international treaties for protection and management of the ETPTD at a supranational level, coordinated and sustained actions must be implemented by competent authorities and other stakeholders at the national, regional, and global levels.

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Part V
Final chapter

The oceans are a collective responsibility

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Humanity depends on the oceans. These vast ecosystems cover most of our planet, interacting with the atmosphere, and hosting a complex web of physical, chemical, and biological processes. Coastal areas, where the oceans meet the land, are particularly dynamic and essential for life. The interaction between land, sea, and atmosphere creates an interconnected system that influences global climate and supports a great diversity of life.

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Oceans and coastal areas are facing increasing pressure due to a combination of natural and anthropogenic factors. Degradation of marine habitats, loss of biodiversity, overfishing, and pollution from substances such as plastics and nutrients are increasingly serious problems. Climate change is further aggravating this situation, causing sea level rise, ocean acidification, and coastal erosion. These alterations threaten the health of marine ecosystems, food security of communities, and coastal infrastructure. Despite these challenges, many coastal communities, especially those in vulnerable situations, depend on the sea for their livelihoods and maintain a close cultural bond with it.

Various coastal and oceanic phenomena do not recognize borders; moreover, their distributions vary over time, some being transboundary, regional, or global. From this, the complexity of coastal management is inferred, as its functioning depends on the health of systems that may be located far away. This characteristic requires the implementation of approaches at regional, local, and global scales. Coastal and oceanic phenomena transcend borders and change over time, with scales ranging from local to global. This complexity makes coastal management a challenge, as it involves considering interconnected systems that may be very distant. Costa Rica, with its extensive experience in managing marine spaces, proposes an integral vision that recognizes the ocean as a complex system and the coasts as communal spaces. This approach, based on academic rigor and social responsibility, seeks to articulate different perspectives and find solutions to the environmental, economic, and social challenges faced by coastal areas.

From the perspective of the United Nations Convention on the Law of the Sea (UNCLOS), this book analyzes the broad vision proposed by national and international ordinances for an informed governance of ocean spaces. Sustainability depends on the ability to build such governance, bringing together the efforts and commitment of all countries to fully comply with their legal obligations through the adoption of effective national legislation. This is a basic requirement to combat pollution and overexploitation of oceanic resources. Although Costa Rica's experience shows progress, it also presents challenges and weaknesses in implementing a coherent regulatory framework. Emerging institutional fragmentation threatens the fulfillment of governmental commitments already made, as the main guarantors of marine space conservation.

A noteworthy experience from Costa Rica, related to the construction of effective governance, is the establishment and expansion of protected areas, such as Cocos Island National Park and the Montes Submarinos Marine Management Area. The successful completion of this process is due precisely to the priority given to integrating institutional, community, academic, and legislative efforts, with the goal of conserving biodiversity and ensuring the sustainability of marine resources, which underpin the well-being of the communities that depend on these resources, as well as other key activities like fishing and tourism. The growing pressure exerted on marine ecosystems should motivate the replication of consultative processes like the one mentioned, in order to establish or expand protected areas, as well as to ensure the effectiveness of their management. It is in these spaces where academia can and should play a leading role, due to its technical capacity, scientific rigor, and independence of judgement. These elements are fundamental when designing the participatory management model necessary to achieve consensus in the conservation and management of ecosystems and resources.

A similar and equally successful process led to the creation and implementation of marine protected areas in Costa Rica, including the Cabo Blanco Absolute Natural Reserve and responsible fishing marine areas. Despite the difficulties derived from the diversity of criteria and interests involved in the creation of these marine areas, their collaborative management and the prioritization of community welfare over individual well-being in the process, led to coordination and cooperation that revitalized fishing communities and diversified catch species.

These experiences are a demonstration that conservation can be a priority for fishermen and fisherwomen, demonstrating the need to control the use of resources as a measure to ensure the local economy and the future of coastal communities. However, it should not be ignored that in Costa Rica's coastal areas, institutional fragmentation prevails, and the State fails to implement binding regulations.

In this scenario, fishing communities are essential for ocean management, and the country's public universities, especially Universidad

Nacional (UNA), are vital in the construction of coastal territories where democratic coexistence and respect for human rights are respected. People engaged in small-scale fishing face problems that exacerbate their vulnerability, currently characterized by marginalization, unemployment, and poverty. Thus, decision-making with the participation of small-scale fishers becomes a valid and effective alternative on the road to sustainability. Undoubtedly, to achieve the effective participation of coastal communities, it is not enough to democratize regulations or involve the institutions concerned; it also involves empowerment and the development of leaderships capable of recognizing prevailing conditions in coastal areas, which are decisive in the joint construction of resilient communities. Governmental responsibility should focus on supporting these leaderships to facilitate the creation of prospective planning at the local, national, and regional levels, ensuring the necessary transformations.

Women have a prominent role in fishing communities, for they are the guardians of knowledge and leaders in the struggle for family survival. This is attested to by the fisherwomen of Barra del Colorado in Costa Rica and Ilhabela in Brazil. These powerful actors are often invisibilized, as are their daily efforts to link cultural values with the determining guidelines for community development. This contradiction must be overcome in the effort to guarantee the rights of all citizens in a country. At the same time, they are part of a global community, with similar identities, struggles, and issues.

Women fishers and their particular sensitivities regarding the space they inhabit validate them as interlocutors in the face of climate change manifestations along the coasts. Physical changes in territories, as in the Caribbean coast of Costa Rica, are not necessarily evident to those who are not directly exposed to them; while academia requires prolonged monitoring of coastal dynamics, these transformations are tangible for women fishers.

Erosive processes are part of coastal dynamics, and a deep analysis of the oceans requires considering them in their complexity, as products of the interaction between natural processes and human activity, with consequences for coastal areas inhabited by one of the most impoverished sectors of the Costa Rican population, as previously described. Research provides scientific data that not only recognizes coastal dynamics but also helps anticipate changing scenarios. Such information is essential for local governments in the preparation or revision of county land use plans, as it helps reduce exposure to events that may endanger lives, destroy ecosystems, and damage coastal infrastructure.

Perhaps tsunamis are even more sporadic events than erosive landslides along coasts, yet the rapid population growth in these areas increases the risk of exposure to these phenomena. As preventive capacities are built, communities' resilience to disasters can increase. In this sense, evacuation maps that accompany their design are ideal, especially if they incorporate contingency plans to be executed inter-institutionally.

A limitation that affects the impact of the Universidad Nacional in its priority areas is the availability of resources and the consequent difficulty these conditions create for mid- and long-term research planning Equally important are the difficulties in innovating monitoring methodologies. Despite these difficulties, coastal dynamics in the Gulf of Nicoya and the Bay of Santa Elena, both territorial spaces of relevance for the national economy and environmental conservation, have been under investigation for several years. The information generated allows modeling of oceanographic parameters and their interactions. Projections could provide the necessary foundation for decision-making in communities, local governments, and at the national level.

Some research conducted at the UNA use seismology as a monitoring tool to reveal the complexity of ocean dynamics and its interactions with the earth's crust. This methodology has been effective for detecting hazards associated with climate change. These innovative technologies provide the scientific community with real-time information on oceanic variations and the challenges these effects pose for preventive and response measures when risks materialize. These advanced technologies are further evidence of the significant contribution that Costa Rica's public universities offer in understanding the delicate balance between human activities, climate fluctuations, and ecosystem dynamics, as well as the increasing destabilizing potential of oceanic phenomena, including the Eastern Tropical Pacific Thermal Dome.

Studies highlight the importance of the aforementioned phenomenon in the economies of countries that benefit from its natural wealth. At the same time, they reveal its growing vulnerability if regulatory measures on resource use and biodiversity protection actions are not implemented. These strategies rely on continuous monitoring of species and ecosystems through coordinated national and international efforts. Equally relevant are other biological monitoring strategies that the UNA has maintained for more than thirty years in strategic coastal areas, to identify conditions that generate harmful algal blooms, as well as the risks of these events on human health and the economy of affected territories. The monitoring and risk response strategy has evolved over time and, in view of the increasingly profound effects of bloom events, requires the implementation of innovations that accelerate measurement processes and facilitate communication with local authorities.

Despite advancements in terms of knowledge, there are fundamental areas that need strengthening to continue on the path of sustainable ocean management, such as:

- Strengthening coherent, integrated monitoring efforts of the world's oceans and coasts, with outcomes that have medium- and long-term impacts, ultimately aiming to conserve, manage, and sustainably use oceanic and coastal resources while minimizing vulnerability and anticipating extreme or ordinary phenomena. Addressing scientific problems of interest in their full complexity, as appropriate, with multi- and interdisciplinary scientific participation.

- Encouraging integrated, planned approaches with long-term investments and cooperation between nations and international organizations.

- Promoting collaboration among scientific groups with common interests to enhance the scope of projects, share existing capabilities, and increase data analysis capabilities.

- Strengthening the development of databases with quality-controlled, historical, and reliable information, including digitized records with metadata, to track changes and forecast regional or global phenomena. Engaging coastal communities, decision-makers, legislators, civil society, international organizations, specialists, and the general public to adopt measures to protect and sustainably use marine and coastal resources while reducing coastal vulnerability.

- Prioritizing funding sources that align with the requirements of high-impact scientific products in terms of spatial and temporal coverage.

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