RESEARCH ARTICLE

Marine and Coastal Management: Maritime Authority Vision in island areas. Archipelago of San Andrés, Providencia y Santa Catalina, Colombian Caribbean

Ordenamiento Marino Costero: Visión de Autoridad Marítima en zonas insulares del archipiélago de San Andrés, Providencia y Santa Catalina, Caribe colombiano

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ABSTRACT

Island territories hold significant importance due to their environmental, economic, and social characteristics, making it necessary to plan and manage their marine and terrestrial spaces. In Colombia, the Archipelago of San Andrés, Providencia y Santa Catalina stands as a primary tourist destination, hosting various maritime activities that have the potential to generate conflicts and impact diverse natural environments. The purpose of this research was to apply the methodology of Marine and Coastal Management: Maritime Authority Vision (MCM:MAV), to analyze the current and future conditions of marine-coastal uses and activities within the islands, as a tool for decision making. Results from this research reveal that the primary contributors to conflict include restricted areas, the Marine Protected Area, the artisanal fishing zone, and the coral reefs. Furthermore, the most suitable zones for the development of maritime activities and their compatibility were defined on the basis of the Allocation and Co-location Model (MAYC in Spanish). The study established the percentages of suitable areas for aquaculture (61.24%), offshore wind farms (48.02%), and submarine cables (48.32%). Finally, through the implementation of the Prioritization Index for Decision Making (IPTD in Spanish) which determined the degree of development trend and representativeness of each use/activity in the area, aquaculture emerges as the sector with the highest growth potential when compared to offshore wind farms and submarine cables.

KEYWORDS: coastal zone management, maritime activities, conflicts, allocation, co-location, future development scenarios, Geographic Information Systems.

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Resumen

Los territorios insulares presentan una gran importancia debido a sus características ambientales, económicas y sociales, por lo que es necesario la planificación y gestión de sus espacios marinos y terrestres. En Colombia, el Archipiélago de San Andrés, Providencia y Santa Catalina es uno de los principales destinos turísticos y en donde se desarrollan varias actividades marítimas que podrían generar conflicto entre ellas y afectar los diferentes ambientes naturales. El propósito de esta investigación fue aplicar la metodología del Ordenamiento Marino Costero: Visión de Autoridad Marítima (OMC:VAM), con el fin de analizar las etapas de condiciones actuales y futuras entre usos/actividades marino-costeras presentes en las islas, como una herramienta para la toma de decisiones. Los resultados indicaron que los usos que más contribuyen al conflicto son las áreas restringidas: el área marina protegida, la zona de pesca artesanal y los corales. Adicionalmente, se definieron las zonas más adecuadas para el desarrollo de actividades marítimas y su compatibilidad a partir del Modelo de Asignación y Colocalización (MAyC), y se establecieron los porcentajes de zonas aptas para los usos de acuicultura (61.24 %), parques eólicos (48.02 %) y cables submarinos (48.32 %). Finalmente, con el establecimiento del Índice de Priorización para la Toma de Decisiones (IPTD), que determinó el grado de tendencia de desarrollo y representatividad de cada uso/actividad en el área, se consideró que la acuicultura es el sector con mayor tendencia de crecimiento con respecto a parques eólicos y cables submarinos.

Palabras clave: *ordenamiento marino costero, actividades marítimas, conflictos, asignación, colocalización, escenarios de desarrollo futuro, sistemas de información geográfica.*

Introduction

In island areas, the growth of sectors related to tourism, fishing, trade and agriculture, among others, as well as urban development, have generated pressure on marine resources. In addition to the above, the lack of management plans that involve both marine and terrestrial components has caused incompatibilities between maritime activities, ecosystems and the different actors (Aldana and Hernández, 2016; Gallego-Cosme, 2014).

The Archipelago of San Andrés, Providencia y Santa Catalina, located in Colombia, is not exempt from this problem, since multiple activities have been carried out in its marine-coastal areas in a disorganized manner, mainly due to the fact that its Land Use Planning (POT in Spanish) took around 15 years (1989-2003) to be approved (Ramírez-Charry, 2019). In turn, the increase in population, which according to the National Administrative Department of Statistics (DANE) was 2.86% between 2005 and 2018 (Government Department of the Archipelago of San Andrés, Providencia and Santa Catalina, 2021), has led to greater conflicts of use for space (Christie, Smyth, Barnes, & Elliott, 2014).

That is why the General Maritime Directorate (Dimar), as the National Maritime Authority, is responsible for the execution of the Colombian State policy in this topic, through the regulation and coordination of maritime activities (Decree Law No. 2324, 1984), the mission, the vision, the institutional principles, the maritime interests, the institutional development strategies projected towards the year 2042 (Dimar, 2022); and the provisions of Conpes 3990 (DNP, 2020a) have addressed the "Marine and Coastal Management: Maritime Authority Vision (MCM:MAV)", which seeks:

> "[...] analyze and assign temporal and spatial distributions of human activities in Colombian jurisdictional waters and coastal areas, in order to achieve the consolidation of the country as a biooceanic power under a holistic approach and comprehensive maritime, river and port security; as well as a national maritime strategy and structure, guaranteeing ecological, economic, and social principles" (Afanador-Franco, Molina-Jiménez, Pusquin-Ospina, Escobar-Olaya, & Castro-Mercado, 2019).

Likewise, due to the COVID-19 contingency that affected the world economy, the MCM:MAV considered the future development trend of marine-coastal activities based on the analysis of global growth under scenarios with and without a pandemic, to facilitate decision-making focused on improving the current and future conditions of the maritime space (Ehler and Douvere, 2009; McGowan, Jay, & Kidd, 2019; Scenario Introduction, 2021).

Taking into account the above, the Caribbean Oceanographic and Hydrographic Research Center (CIOH) carried out the application of the MCM:MAV methodology in the Archipelago of San Andrés, Providencia y Santa Catalina, as a contribution that facilitates the management of the territory for decision-makers, as it is an area with great environmental importance and a high offer of tourism plans.

According to the Colombian Association of Travel and Tourism (Anato, 2023), the Archipelago is the sixth department with the highest number of tourist arrivals, both national and international, and it is considered the most dependent on tourism in the country, since it is estimated that 70% of its economy revolves around this activity (Government Department of the Archipelago of San Andrés, Providencia and Santa Catalina, 2019). Fishing is also an important economic activity. However, it is not enough to supply the needs of the community, therefore, the implementation of aquaculture projects could be an option with which fishermen agree to improve their conditions and those of the environment (Government of the Archipelago of San Andrés, Providencia and Santa Catalina, n.d.; Sarmiento-Guerrero & Pérez-Walteros, 2021). In terms of energy generation, the aim is to change the use of fossil fuels for renewable energies that meet the needs of the islanders, help reduce costs and dependence on diesel (Arias and Duffis, 2017; Más Comunidad, 2023). Additionally, due to their geographical location, submarine cables are an important tool for establishing the necessary telecommunications for connectivity and access to information, and to deal with any situation that arises on the islands (Asomovil, 2021).

In this research, the MCM:MAV methodology was applied based on the provisions of the publications entitled: 'Conflictos de Uso en el Proceso de Ordenamiento Marino Costero: Visión de Autoridad Marítima. Departamento de Bolívar-Colombia' (Afanador-Franco *et al.,* 2019), 'Ordenamiento Marino Costero: Visión de Autoridad Marítima. Departamento de Bolívar - Colombia' (Afanador-Franco *et al.,* 2021), 'Modelo de asignación y colocalización de actividades marítimas para el ordenamiento marino costero en el Departamento de Bolívar, Colombia' (Afanador-Franco *et al.,* 2022), 'Zonificación de actividades marítimas bajo escenarios de desarrollo futuro en los departamentos de Bolívar, Sucre y Córdoba, Colombia' (Afanador-Franco, Molina-Jiménez, Pusquin- Ospina, Barrientos, Banda-Lepesquer, & Castro-Mercado*,* 2023).

Study Area

The Archipelago of San Andrés, Providencia y Santa Catalina is located in the Caribbean Sea, northwest of Colombia, between 12º and 16º North latitude and between 78º and 82º West longitude (Fig. 1), occupying an area of 180,000 km^2. It was declared by the United Nations Educational, Scientific and Cultural Organization (UNESCO), in 2000, as a Seaflower Biosphere Reserve, due to its importance for marine and coastal ecosystems. It includes the islands of San Andrés, Providencia and Santa Catalina, the islands of Courtown Cays, Serranilla Bank, Southwest Cays, Roncador Bank, Queena Reef, Serrana Bank, Alice Shoal and Bajo Nuevo Bank (Carvajal, 2009; CCO, 2015; CCO, n.d.; Decree 1946 of 2013; Díaz, 2005).

It has a great wealth of marine biodiversity and important ecosystems such as mangroves, coral reefs and seagrasses, among others. It is characterized by a humid climate from May to November, and a dry climate from December to April, influenced by the NE trade winds; with an average temperature of 28ºC and high humidity during most of the year (Dagua, Torres, & Monroy, 2018). Additionally, it is located within the Caribbean hurricane belt, which is evident with the passage of several of these events throughout history, with an occurrence until 2010 of approximately 0.54 events/year, of which only some have reached the coast (CIOH, 2010; Ortiz-Royero, 2012; Ortiz-Royero, Plazas, & Lizano, 2015; Rey *et al.,* 2019; Rey *et al.,* 2021).

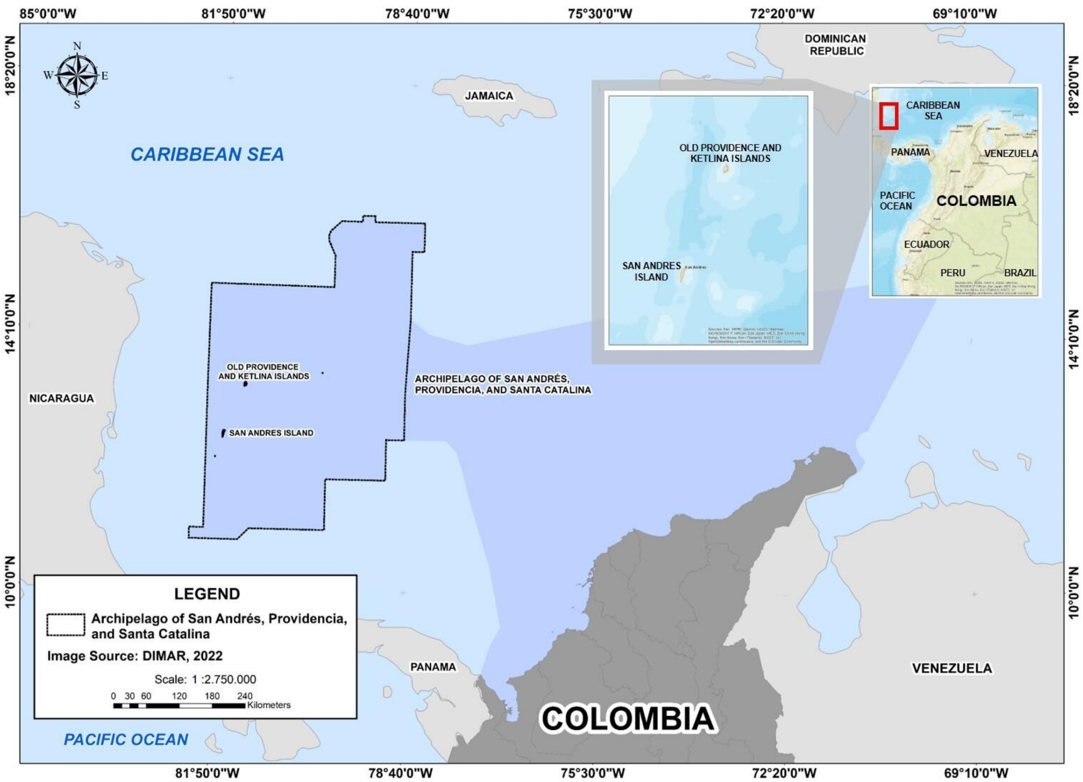

Figure 1. Location of the Archipelago of San Andrés, Providencia y Santa Catalina.

The Archipelago of San Andrés, Providencia y Santa Catalina is located in the upper part of Nicaragua, northwest of the Colombia basin, and it presents a NNE-SSW trend with a volcanic origin in the early Cenozoic, represented by lava flows and pyroclastic and epiclastic deposits. Subsequently, the subsidence of these volcanoes and the deposition of reef limestones defined the geomorphological features observed so far (Carvajal, 2009; Case *et al.,* 1990 in Idárraga-García, García-Varón, & León-Rincón, 2021; Dimar-CIOH, 2013; Geister & Díaz, 2007; Idárraga-García & León-Rincón, 2019; Milliman and Supko, 1968, in Díaz, 2005).

According to Idárraga-García *et al.* (2021), the Archipelago of San Andrés, Providencia y Santa Catalina corresponds to the geomorphological province called the Volcanic Province of the Western Caribbean, which is represented by geoforms of volcanic and structural origin, such as seamounts, guyots, spurs, volcanic peaks, basins limited by faults, and structural columns. Regarding coastal geomorphology, there are units associated with low coasts and high coasts, such as beaches, coastal lagoons, coastal bars, reef bars, dunes, floodplains, hill systems, and elevated abrasion platforms and coral terraces (Carvajal, 2009; Dimar-CIOH, 2013).

Methodology

The MCM:MAV in the Archipelago of San Andrés, Providencia y Santa Catalina, was applied following the methodology proposed by Dimar in Afanador-Franco *et al*. (2019, 2021, 2022 and 2023), which consists of the following stages:

Establishing the elements of governance

Turning the country into a biooceanic power was established as a strategic objective, in alignment with the National Development Plan - Colombia World Power of Life 2022-2026, in its axes of transformation of water management, productive transformation, internationalization and climate action. In addition, a series of technical aspects were defined, such as the scales of representation, the different types of uses/activities, cartographic conformation and spatial documentation.

Pre-planning stage

In this phase, through secondary information, primary direct users of the resources who can contribute to the conflicts were identified, followed by secondary actors, corresponding to the different entities that regulate the activities present in the Archipelago. They answered the following questions: Who should be involved in the process? When should they be summoned to the process? How should they be involved? (Maguire, Potts, & Fletcher, 2012; Afanador-Franco *et al.,* 2019; 2021).

Analysis of current conflict-related conditions

The spatial and photographic documentation of marine-coastal activities was carried out, through fieldwork, by means of surveys using the ArcGIS Survey 123 tool, in which the categories of use/activity were defined, taking into account the provisions of Decree Law 2324/84.

According to the above information and through the judgment of experts, the multicriteria analysis based on the Analytic Hierarchy Process (AHP) was applied, which consists of establishing comparisons between pairs of uses through relative values using an importance scale (Malczewski, 1999; Afanador-Franco *et al.,* 2019, 2021). These were presented in a cross-matrix of pair compensation, in which the crossovers between the uses in the study area were analyzed and the overlapping conflicts were defined.

In addition, three matrices were made corresponding to: *i)* Justification matrix, in which the reason for the assignment of the important values was briefly explained, *ii)* Normalized matrix of compensation by pairs, in which, based on a mathematical process, the values assigned in the first matrix were adjusted to a range between 0 and 1, and *iii*) Matrix of weights, in which the weights of each use were calculated, averaging their respective conflicts and identifying the uses that contribute most to the conflict.

Then, using geographic information systems (GIS) tools, two approaches were made to visualize and present the spatial distribution of the conflicts. The first consisted of quantifying the index of conflict between pairs of uses, taking into account the weights of each one; and the second analyzed the amount of overlap between the uses that have the most conflicts.

Finally, the maps corresponding to each of the approaches were generated and the free areas in which there were no uses or conflicts were defined, thus they may be suitable for the development of future maritime activities. The detailed process of this stage is described in Afanador-Franco *et al.,* 2019, 2021 (Fig. 2).

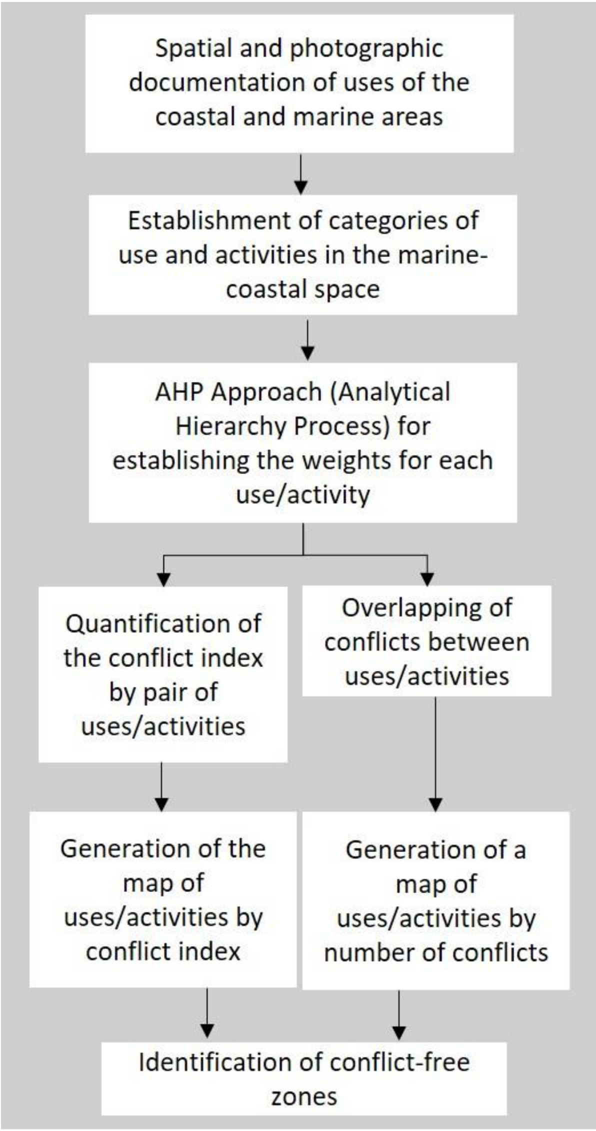

Figure 2. Methodological process for the analysis of current conflict-related conditions.

Analysis of future conditions

In this stage (Fig. 3), the Assignment and Co-location Model (MAYC) was implemented, seeking to spatially establish the best location of uses with a tendency to development, in places that meet certain technical and environmental criteria. Based on this, scenarios are proposed that allow the identification of opportunities, conflicts and compatibilities to guide decision-making (Afanador-Franco *et al.,* 2021).

In this case, the scenarios before and after the COVID-19 pandemic were considered, and the characteristics of future growth and development for the uses of aquaculture, wind farms and submarine cables were evaluated (Afanador-Franco *et al.,* 2022, 2023).

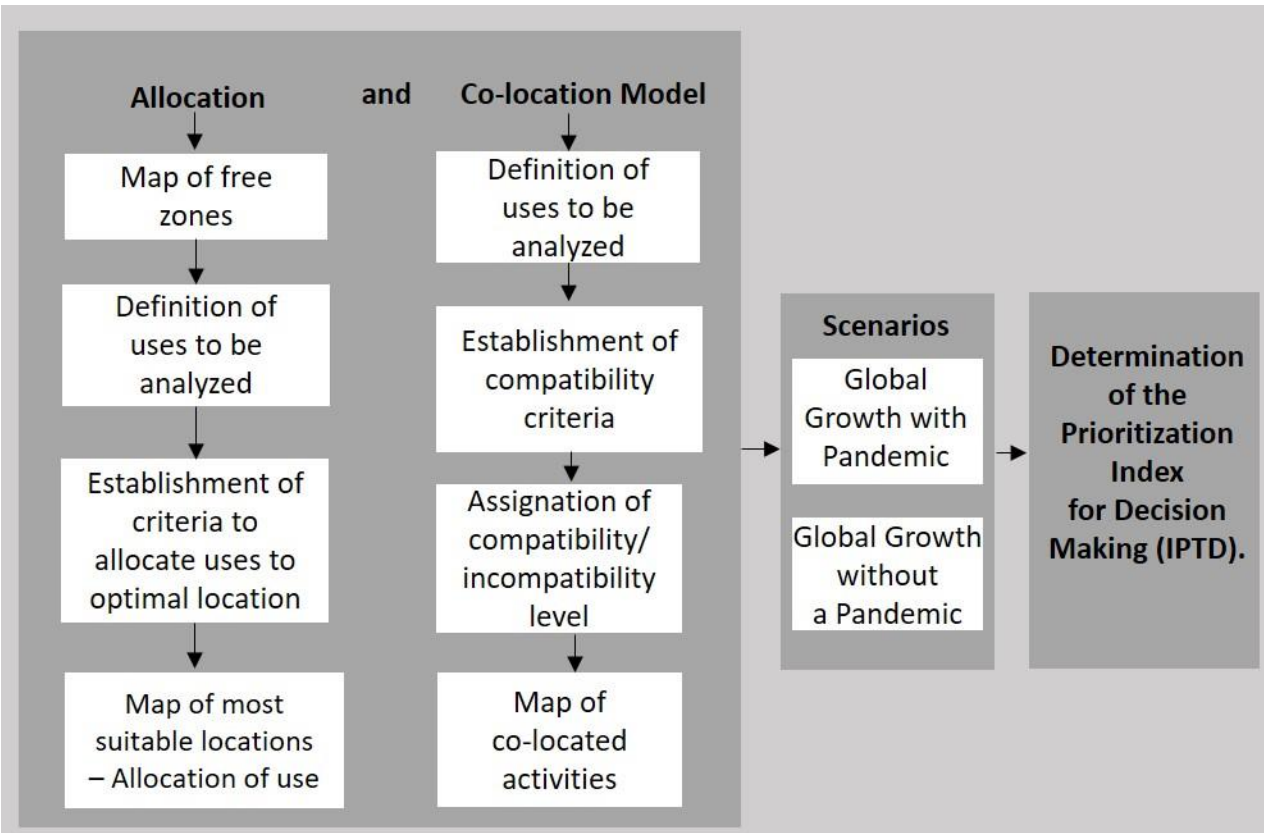

Figure 3. Methodological process for the analysis of future conditions.

Allocation analysis. The technical and environmental criteria (depth, type of bottom, currents, waves, among others) were established through bibliographic information, expert judgment and availability of data. They were subdivided into sub-criteria of suitable, moderately suitable and unsuitable conditions; then they were cross-referenced through GIS tools to determine the location of possible suitable areas for the future development of a use in areas free of maritime activities, as it is today. The detailed process of this stage is described in Afanador-Franco *et al.,* 2022.

Co-location analysis. This stage concentrated on the development of uses in the same geographical space, minimizing their conflicts by means of a compatibility scale between pairs of uses that evaluates the positive and/or adverse effects. A matrix was built with the criteria established in the allocation analysis and with variables of efficiency and effectiveness (proximity to the coast, tourist vocation, water quality, among others) defined for each use. The detailed process of this stage is described in Afanador-Franco *et al.,* 2022.

Future development scenarios and percentage of future trend. The following scenarios were defined: *i)* Global Growth without a Pandemic, in which it is assumed that the COVID-19 pandemic did not occur and that the growth trends of maritime activities will continue until 2030. *(ii)* Global Growth with Pandemic, which estimated the recovery of future maritime development trends during COVID-19 until 2030. For each activity, the percentage of future trend under each scenario was established through bibliographic information (Afanador-Franco, Molina-Jiménez, Pusquin-Ospina, Barrientos, Banda-Lepesquer, & Castro-Mercado, 2023).

Determination of the Prioritization Index for Decision Making (IPTD). Taking into account the MAYC analysis and the scenarios defined for each activity, the IPTD was calculated, based on the development trend and the relationship between the area of the suitable area and the total study area, which allows defining, among several activities, which one should be given priority in the event that several requests for the space are submitted to be developed at the same time (Afanador-Franco *et al.,* 2023).

To calculate the IPTD between several uses, a normalization was performed, in which values close to 1 indicate which use should be prioritized, since it has a greater growth and representativity tendency. The detailed process of this stage is described in Afanador-Franco *et al.,* 2023.

Results

Governance elements

In the MCM:MAV, national and international decrees, policies, conventions and/or agreements were identified as:

- Decree Law 2324 of 1984, which establishes that the General Maritime Directorate has as its purpose the regulation, direction, coordination and control of maritime activities.
- Decree 5057 of 2009, which defines the functions of the Director General of Maritime Affairs, specifying the responsibility of planning, directing, coordinating and evaluating the regulations for the development, control and surveillance of maritime activities.
- Dimar's Strategic Plan 2042 (Dimar, 2022), which defines the strategic objectives corresponding to "directing the promotion and safe and sustainable development of maritime activities" and "influencing the national and international sphere to consolidate maritime interests."
- The General Policy of Land Use (PGOT) (DNP, 2020b), which aims to "guide the physical, socio-spatial and political-administrative organization of the national territory."
- The National Ocean and Coastal Spaces Policy (Pnoec) (CCO, 2018) and the National Council for Economic and Social Policy Conpes-3990 (DNP, 2020a) that stipulate the inter-institutional objective of turning Colombia into a biooceanic power, through the connection of the continental territory to the oceanic territory.
- The National Development Plan 2022- 2026 (DNP, 2023), which establishes the axes of transformation related to land use planning around water (functional approach to land use) and productive transformation, internationalization and climate action (use of clean energy).
- The 1974 International Convention for the Safety of Life at Sea and the 1978 SOLAS 74/78 protocol, related to the standards that merchant ships must comply with to carry out safe navigation.
- The International Convention for the Prevention of Pollution from Ships, which focuses on issues of oil pollution, the handling of harmful liquid substances, the transport of harmful substances, and sewage and garbage from ships: MARPOL 73/78.

In addition, information on maritime activities was compiled from data available from different entities at the national level related to the management and planning of coastal marine spaces, and for an adequate representation of the uses/activities identified between the limit of public use assets and 200 nautical miles, scales between: 1:1 750 and 1:820 000, under the MAGNA-SIRGAS coordinate system with single origin (CTM12) (Afanador-Franco *et al.,* 2019, 2021).

Pre-planning

For the purposes of the development of coastal marine planning, in the study area of the Archipelago of San Andrés, Providencia y Santa Catalina, 517 primary actors were identified related to activities such as fishing (1), tour operators (3), hotels (188), restaurants (161), water sports (29), commercial sector (74), marinas (8), institutional sector (49), cooperatives (1), submarine cables (3), in addition to 32 secondary actors from different sectors such as defense, environment, tourism, fisheries and telecommunications. The results obtained during the MCM:MAV will be shared with all of them in order to provide feedback on the process (Afanador-Franco *et al.,* 2019, 2021).

Current conflict-related conditions

The categories of uses/activities were established in accordance with Decree Law 2324 of 1984, corresponding to maritime activities in which Dimar has interference, such as land uses and a natural base classified by ecosystem function, according to the definition of De Groot, Wilson and Boumans (2002) and Portman (2016). 38 uses/activities were identified, which correspond to 32 uses categorized into 11 maritime activities and 6 uses included in the classification of land uses.

The information was compiled from available databases provided by different entities such as Dimar, the National Hydrocarbons Agency (ANH), the Providencia Territorial Land Use Plan, Tremarctos Colombia 3.0, National Natural Parks of Colombia, the Information System for the Management of Mangroves of Colombia (SIGMA), the Institute of Marine and Coastal Research "José Benito Vives de Andréis" (Invemar), the Colombian Institute of Rural Development (Incoder) and the University of Bogotá "Jorge Tadeo Lozano" (Table 1).

Table 1. Categories of uses/activities for the coastal marine zone of the Archipelago of San Andrés, Providencia y Santa Catalina.

Item	Maritime activities (Decree-Law 2324/84)	Use/Activity
1	Maritime Signaling	Buoys & Lighthouses
2	Maritime traffic control	Anchoring areas
3		Navigation channels
4	Construction, operation and management of port facilities	Port concessions
5	Administration and development of the coastal zone	Maritime concession for submarine outfalls
6		Hotel maritime concession
7		Maritime concession restaurants
8		Marine Maritime Concession - Marinas
9	Placement of any type of structure, fixed or semi-fixed works on the marine ground or subsoil	Submarine cables
10		Underwater pipeline
11	Conservation, preservation and protection of the marine environment	Threatened species
12		Concentration of birds
13		Concentration of mammals
14		Reptile concentration
15		Regional National Parks
16		National Natural Parks
17		Marine protected area
18		Seagrasses
19		Corals
20		Artisanal fishing area
21		White fishing area

Item	Maritime activities (Decree-Law 2324/84)	Use/Activity
22	Use, protection and preservation of coastlines	Public use goods - beaches
23		Public use goods - low tide
24		Mangrove
25	Search and extraction/retrieval of antiques or shipwrecked treasures	Shipwrecks
26	Recreation and marine nautical sports	Diving
27		Water sports area
28	Dredged fills and ocean engineering works	Coastal protection works
29		Dredged fills and ocean engineering works
30	Other marine uses and/or exploitation	Restricted areas
31		White fishing route
32		Artificial reefs
33	Land uses	Urban area
34		Tourism
35		Institutional
36		Animal husbandry
37		Agriculture
38		Beaches with a tourist vocation

According to what was obtained through the AHP approach, the uses that contribute the most to the conflict correspond to restricted areas, marine protected areas, artisanal fishing areas, beaches with a tourist vocation and corals (Table 2, Fig. 4). On the other hand, the maritime activities with the highest number of conflicts identified from the overlaps for the Archipelago of San Andrés, Providencia y Santa Catalina correspond to the artisanal fishing zone, restricted areas, marine protected area, seagrasses and corals (Table 3, Fig. 5).

Finally, the map of conflict-free zones and the map of use-free zones were generated, as a result of a process with GIS tools in which the areas occupied by conflicts and by the different uses/activities, respectively, are extracted (figures 6 and 7).

Table 2. Uses that contribute most to conflict in the marine coastal area of the Archipelago of San Andrés, Providencia y Santa Catalina.

Use/Activity	Weight
Restricted areas	0.1221
Marine protected area	0.0988
Artisanal fishing area	0.0833
Beaches with a tourist vocation	0.0553
Corals	0.0459

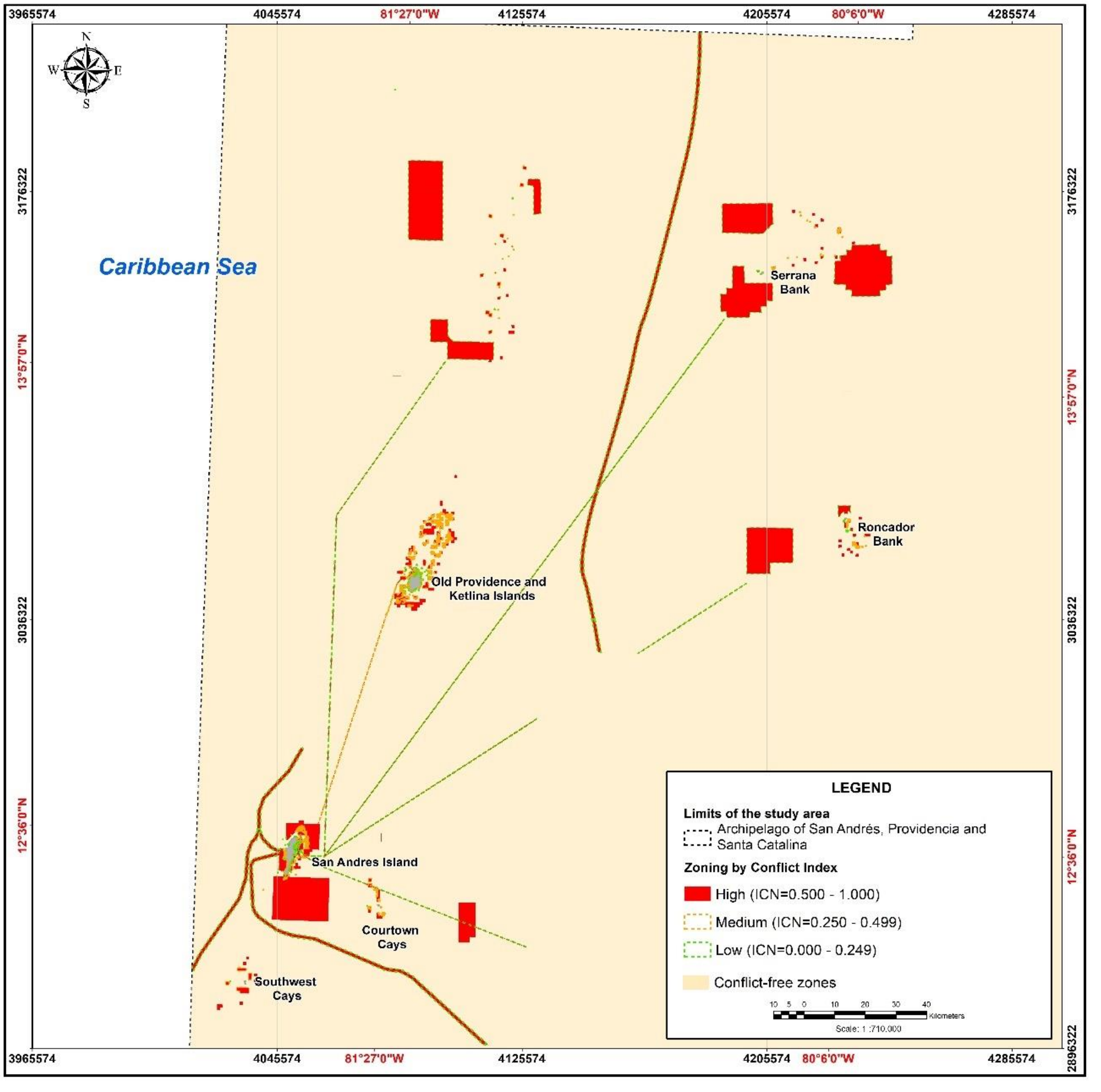

Figure 4. Zoning map by conflict index in the Archipelago of San Andrés, Providencia y Santa Catalina.

Table 3. Uses with more overlaps in the coastal marine area of the Archipelago of San Andrés, Providencia y Santa Catalina.

Use/Activity	Conflicts
Artisanal fishing area	19
Restricted areas	19
Marine protected area	17
Seagrasses	15
Corals	15

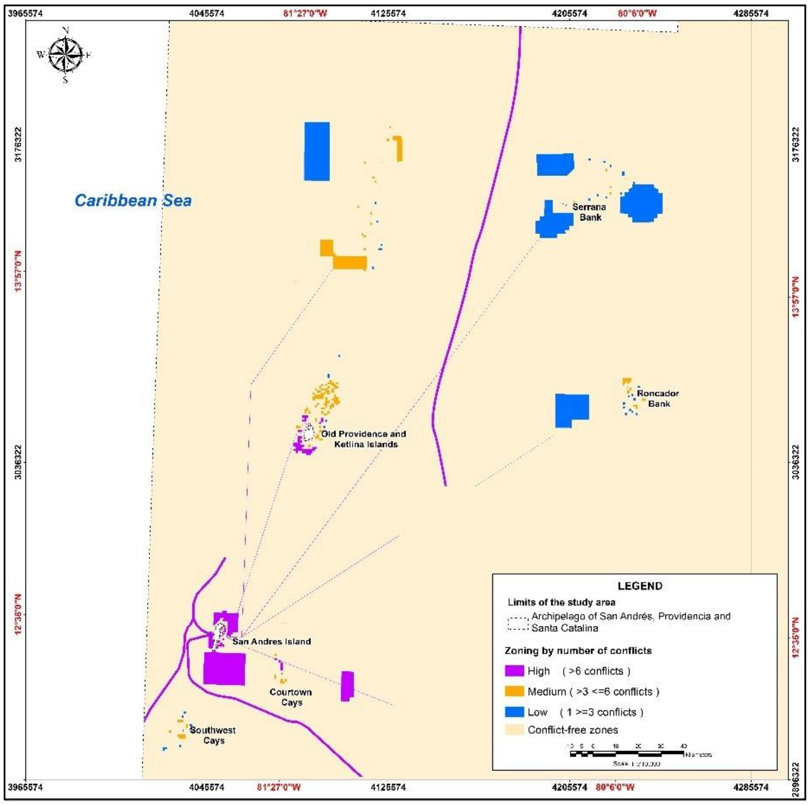

Figure 5. Zoning map by number of conflicts in the Archipelago of San Andrés, Providencia y Santa Catalina.

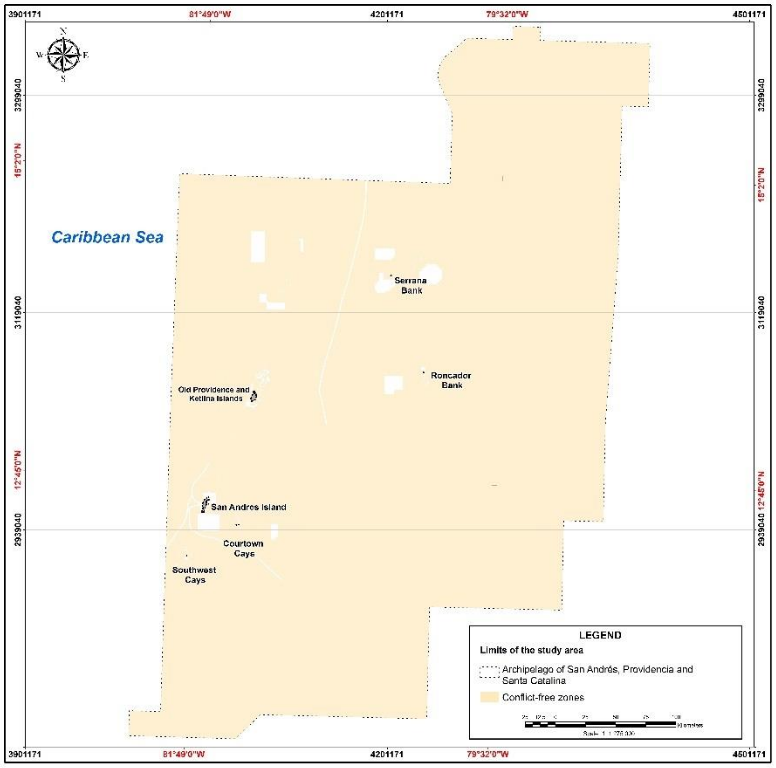

Figure 6. Map of conflict-free zones in the Archipelago of San Andrés, Providencia y Santa Catalina.

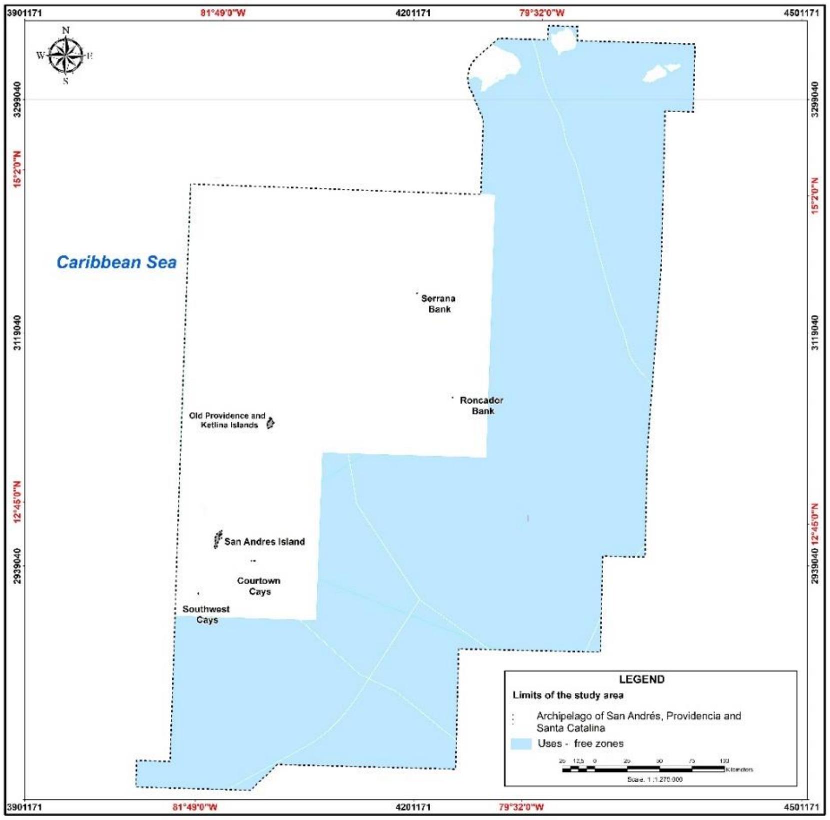

Figure 7. Map of free use zones in the Archipelago of San Andrés, Providencia y Santa Catalina.

Future conditions

Allocation. Aquaculture, wind farms, and submarine cable activities were selected because they present a greater trend of future development in both economic and social terms, thus the most suitable areas for their location and development in the study area were established (Afanador-Franco *et al.,* 2022).

Aquaculture. The determination of areas suitable for future aquaculture development was defined using the available oceanographic criteria and data: seabed type, swell period, significant wave height, currents and possible effects on sediments. In this case, depth was not taken into account, because it varies depending on the species to be grown (Table 4; Fig. 8).

Table 4. Technical and environmental criteria used in the establishment of the most suitable areas for the development of aquaculture.

Criterion	Weight of the criterion	Sub-criteria	Weight of the sub-criterion	Category	* Weighted weight	Source
Type of seabed	0.20	a) Sandy	0.5	Suitable	0.100	Meindl, 1996; Rojo, 2016; Cardia, Ciattaglia, & Corner, 2017; Ivars, 2017; Queensland Government, 2019
		b) Rocky	0.35	Moderately suitable	0.070	
Swell period (T)	0.12	a) 1.9 s < T ≤ 359 s	0.5	Suitable	0.060	Munk, 1950 in Palomino, Almazán, & Arrayás, 2001; Rubino, 2008; Cavia del Olmo, 2009; Kapetsky, Aguilar, & Jenness, 2013; COWI & Ernst, 2013; López and Ruiz, 2015

Criterion	Weight of the criterion	Sub-criteria	Weight of the sub-criterion	Category	* Weighted weight	Source
Significant wave height (Hs)	0.13	a) 0.59 m < Hs ≤ 6.9 m	0.5	Suitable	0.065	Munk, 1950 in Palomino, *et al.,* 2001; Rubino, 2008; Cavia del Olmo, 2009; Kapetsky *et al.,* 2013; COWI & Ernst, 2013; López and Ruiz, 2015
Current speed (Wc)	0.25	a) 0.13 m/s < Wc ≤ 1 m/s (Average)	0.5	Suitable	0.125	Milne, 1976; Carroll, Cochrane, Fieler, Velvin, & White, 2003; Stigebrandt, 2011; Kapetsky *et al.,* 2013; COWI & Ernst, 2013; López & Ruiz, 2015
		b) 0 m/s ≤ Wc ≤ 0.13 m/s (Slow)	0.35	Moderately suitable	0.087	
Direct destruction	0.30	a) Sediments	0.4	Suitable	0.120	Handy & Poxton, 1993; Boyd, 1995; FAO, 2006; Pérez, García, Invers, & Ruiz, 2008; Herbeck, Unger, Wu, & Jennerjahn, 2013; Rabasso, 2016

**weighted weight = criterion weight x subcriterion weight*

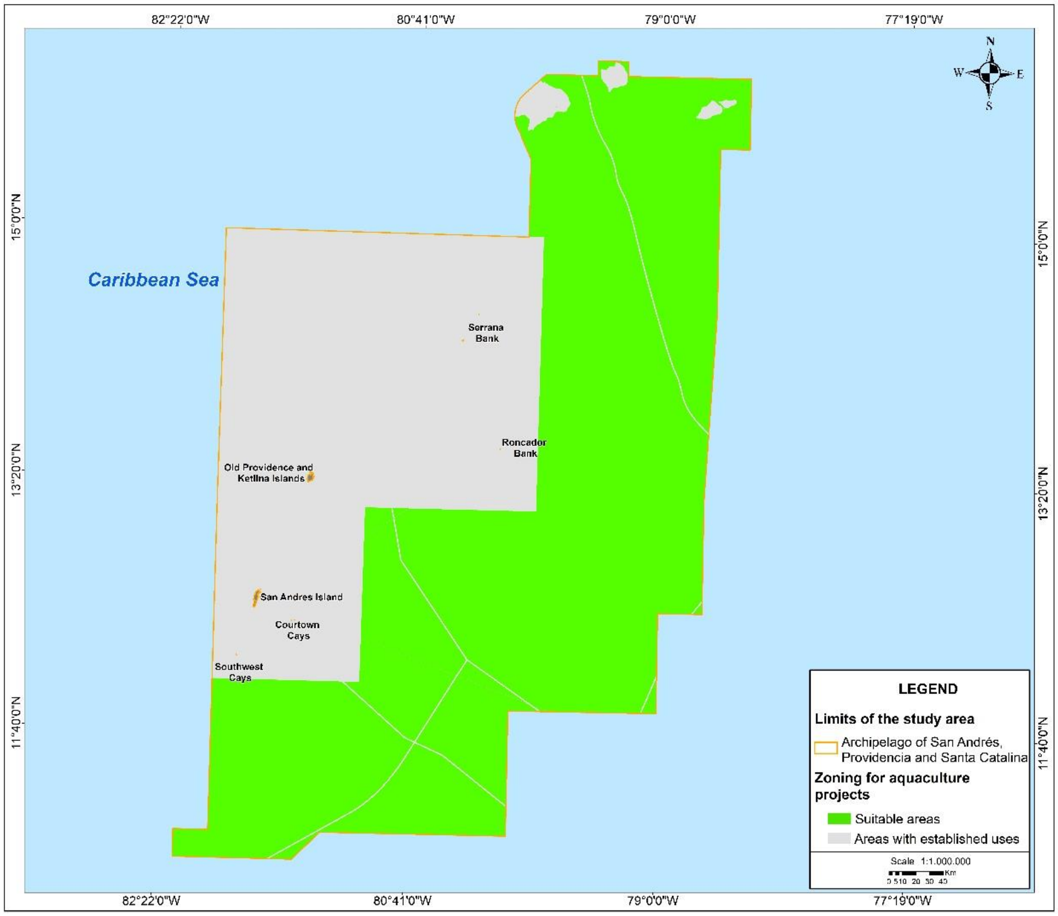

Figure 8. Map of the location of areas suitable for the development of aquaculture projects in the jurisdiction of the Archipelago of San Andrés, Providencia y Santa Catalina.

Wind farms. The criteria used for the optimal location of wind farms were: depth, currents, significant wave height, wind speed at an altitude of 150 m with respect to sea level, type and slope of the bottom, in addition to the possible effects on sediments (Table 5; Fig. 9).

Table 5. Technical and environmental criteria used in the establishment of the most suitable areas for the development of wind farms.

Criteria	Weight of the criterion	Sub-criteria	Weight of the sub-criterion	Category	*Weighted weight	Source
Depth (P)	0.25	a) 0 m – 60 m	0.7	Suitable	0.175	Usón, 2014; Fugro Marine Geoservices Inc., 2017; Vagiona and Kamilakis, 2018
		b) > 60 m	0.3	Moderately suitable	0.075	
Type of seabed	0.12	a) Sandy	0.5	Suitable	0.060	Boehlert & Gill, 2010; Prado, 2018; Xu *et al.*, 2020
		b) Mud and silt	0.35	Moderately suitable	0.042	
Seabed slope (Pf)	0.11	a) 0 % - 3 %	0.5	Suitable	0.055	Malhotra, 2010; Xu *et al.,* 2020
		b) 3 % < x ≤12 %	0.35	Moderately suitable	0.038	
Current speed (Wc)	0.03	a) 0 – 1.75 m/s	0.7	Suitable	0.021	Kapetsky *et al.,* 2013; González, 2007; Esteban, 2009; Loughney, Wang, Bashir, Armin, & Yang, 2021
		b) > 1.75 m/s	0.3	Moderately suitable	0.009	
Significant wave height (Hs)	0.04	a) 0 – 5 m	0.5	Suitable	0.020	Loughney *et al.,* 2021
		b) 5 m < Hs ≤ 8 m	0.35	Moderately suitable	0.014	
Wind speed (V)	0.28	a) >8 m/s	0.8	Suitable	0.224	Baban & Parry, 2001; Sesma, 2020
Direct destruction	0.09	a) Sediments	0.5	Suitable	0.045	Mariyasu, Allain, Benhalima, & Claytor, 2004; Inger *et al.,* 2009; Wilhelmsson *et al.*, 2010
Sediment plume generation	0.08	a) Sands	0.6	Suitable	0.048	NOAA, 2007; Vaselli, Bertocci, Maggi, & Benedetti-Cecchi, 2008

**weighted weight = criterion weight x subcriterion weight*

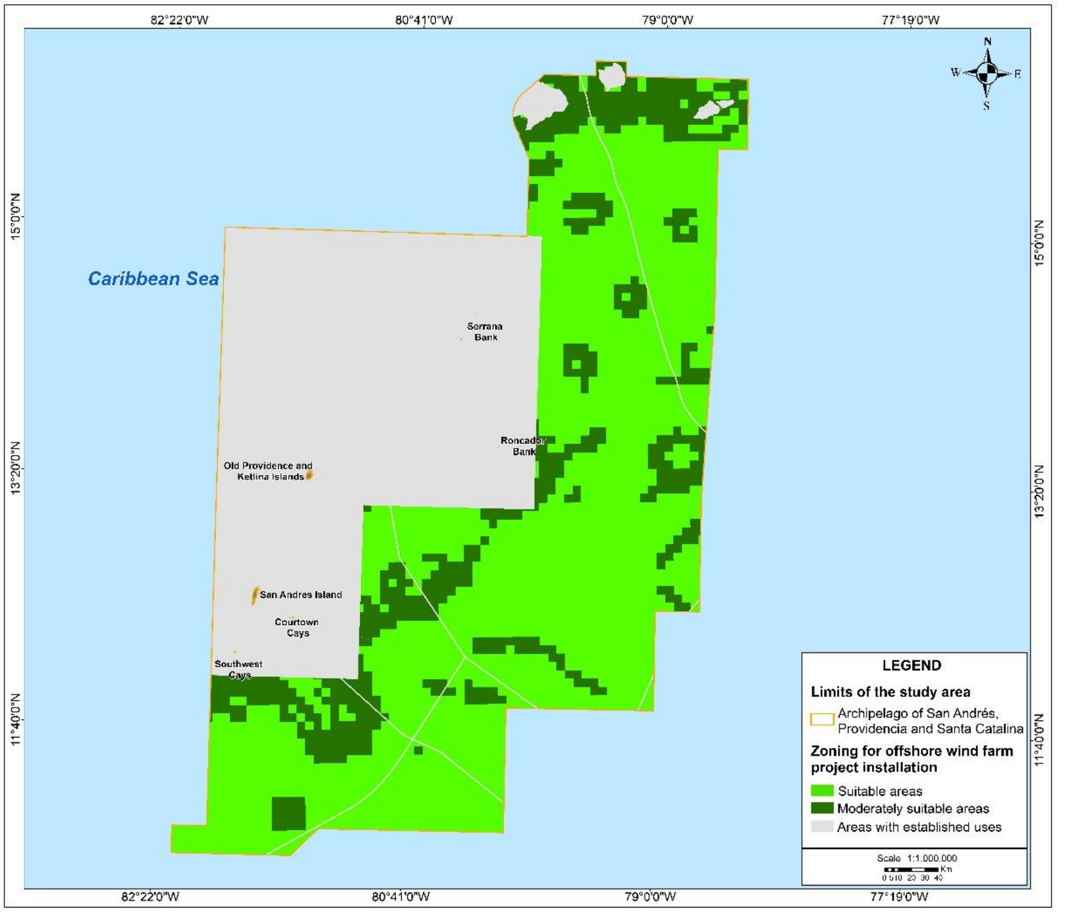

Figure 9. Map of the location of suitable and moderately suitable areas for the development of wind farms in the Archipelago of San Andrés, Providencia y Santa Catalina.

Submarine cables. The determination of the areas suitable for the future development of submarine cables was defined using criteria and available oceanographic data, slope and type of seabed, swell period, significant wave height, currents, possible effects on coastal marine ecosystems and the generation of sediment plumes (Table 6; Fig. 10).

Table 6. Technical and environmental criteria used in the establishment of the areas most suitable for the development of submarine cables.

Criteria	Weight of the criterion	Sub-criteria	Weight of the sub-criterion	Category	*Weighted weight	Source
Seafloor slope (Pf)	0.25	a) Pf ≤ 3 % b) 3 % of < Pf ≤ 12 %	0.5 0.35	Suitable Moderately suitable	0.125 0.0875	Carter *et al.* (2009), Álvarez (2017); Taormina *et al.*, (2018).
Type of seabed	0.20	a) Sandy b) Mud and silt	0.5 0.35	Suitable Moderately suitable	0.1 0.07	Almazán, Palomino and García, (200); Carter *et al.* (2009); Worzyk (2009); Álvarez (2017)
Deep currents (Wc)	0.10	a) 0 m/s ≤ Wc ≤ 1.75 m/s b) Wc > 1.75	0.6 0.4	Suitable Moderately	0.06 0.04	Carter *et al.* (2009); Cavia del Olmo (2009); Guande, Yancong Peng, Chengkai, Xiaoli, and Yang,

		m/s		suitable		(2013)

Criteria	Weight of the criterion	Sub-criteria	Weight of the sub-criterion	Category	*Weighted weight	Source
Swell period (T)	0.05	a) T ≤ 1.9 s b) 1.9 s < T ≤ 359 s	0.5 0.35	Suitable Moderately suitable	0.025 0.0175	Munk (1950) en Palomino, *et al.*, (2001); Carter, *et al.* (2009), and Cavia del Olmo (2009).
Significant wave height (Hs)	0.07	a) Hs ≤ 0.59 m b) 0.59 m < Hs ≤ 6.9 m	0.5 0.035	Suitable Moderately suitable	0.035 0.0245	Carter et al., (2009) y Cavia del Olmo (2009)
Direct destruction	0.18	a) Sediments	0.5	Suitable	0.09	Carter *et al.* (2009); Andrulewicz, Napierska y Otremba (2002); Taormina *et al.* (2018)
Sediment plume generation	0.15	a) Sands	0.6	Suitable	0.09	Taormina *et al.* (2018); OSPAR (2009); ESSO (2008); Newcombe and MacDonald (1991); Pinilla, Gutiérrez, & Ulloa-Delgado (2007)

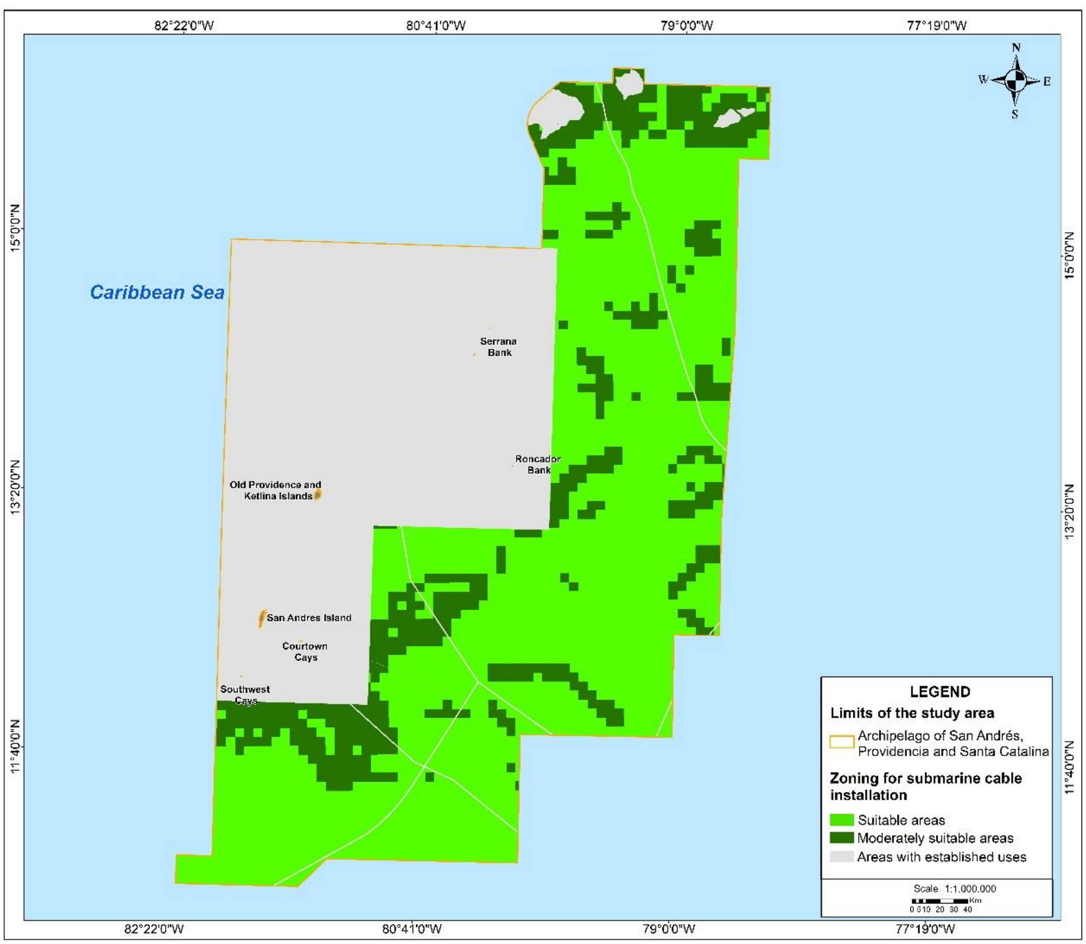

Figure 10. Map of the location of suitable and moderately suitable areas for the installation of submarine cables in the Archipelago of San Andrés, Providencia y Santa Catalina

Co-location

This analysis was based on the elaboration of a cross-matrix between pairs of uses (aquaculture, marine-jetties, submarine cables and wind farms). It took into account the average of the values obtained from the technical/environmental criteria and the efficiency/effectiveness variables established through expert judgment, to determine whether the two uses are mutually improving, do not interfere with each other or negatively affect each other, where values close to 1 indicate greater compatibility between maritime activities (Afanador-Franco *et al.,* 2022) (Table 7).

Table 7. Analysis of the level of compatibility of the uses evaluated.

Uses	Technical and environmental criteria	Efficiency and effectiveness variables	Average	Expression of compatibility/ incompatibility
Aquaculture *vs.* wind farm	0.080	0.750	0.415	Conditionally incompatible
Aquaculture *vs.* submarine cables	0.075	0.750	0.412	Conditionally incompatible
Wind farm *vs.* submarine cables	0.100	1.000	0.550	Conditionally compatible

Additionally, the IPTD was calculated taking into account the two established scenarios. It reflects both the degree of development trend for aquaculture, offshore wind farms and submarine cables, as well as the representativeness between each pair of uses (tables 8 to 10 and figures 11 to 13) (Afanador-Franco *et al.,* 2023; Communications Regulation Commission, 2020; Echeberría, 2020; GWEC, 2019, 2021; FAO, 2016, 2020; Research and Markets, 2020, 2022; TeleGeography, 2022).

Table 8. Prioritization Index for Decision-Making under the non-pandemic and pandemic scenarios for aquaculture uses and offshore wind farms.

Scenario	Use/Activity	Growth trend (%)	Total area of the suitable areas (km^2)	IPTD	IPTD Standardized
No pandemic	Aquaculture suitable areas	46 (FAO 2016, 2020)	101663.8963	0.4597	0.7302
	Offshore wind farms suitable areas	17 (GWEC, 2019)	79717.3333	0.1332	0.2116
	Offshore wind farms moderately suitable areas	17 (GWEC, 2019)	21933.91055	0.0367	0.0582
With a pandemic	Aquaculture Suitable areas	42 (FAO 2020).	101663.8963	0.4197	0.5834
	Offshore wind farms suitable areas	30 (GWEC 2021).	79717.3333	0.2351	0.3267
	Offshore wind farms moderately suitable areas	30 (GWEC 2021).	21933.91055	0.0647	0.0899

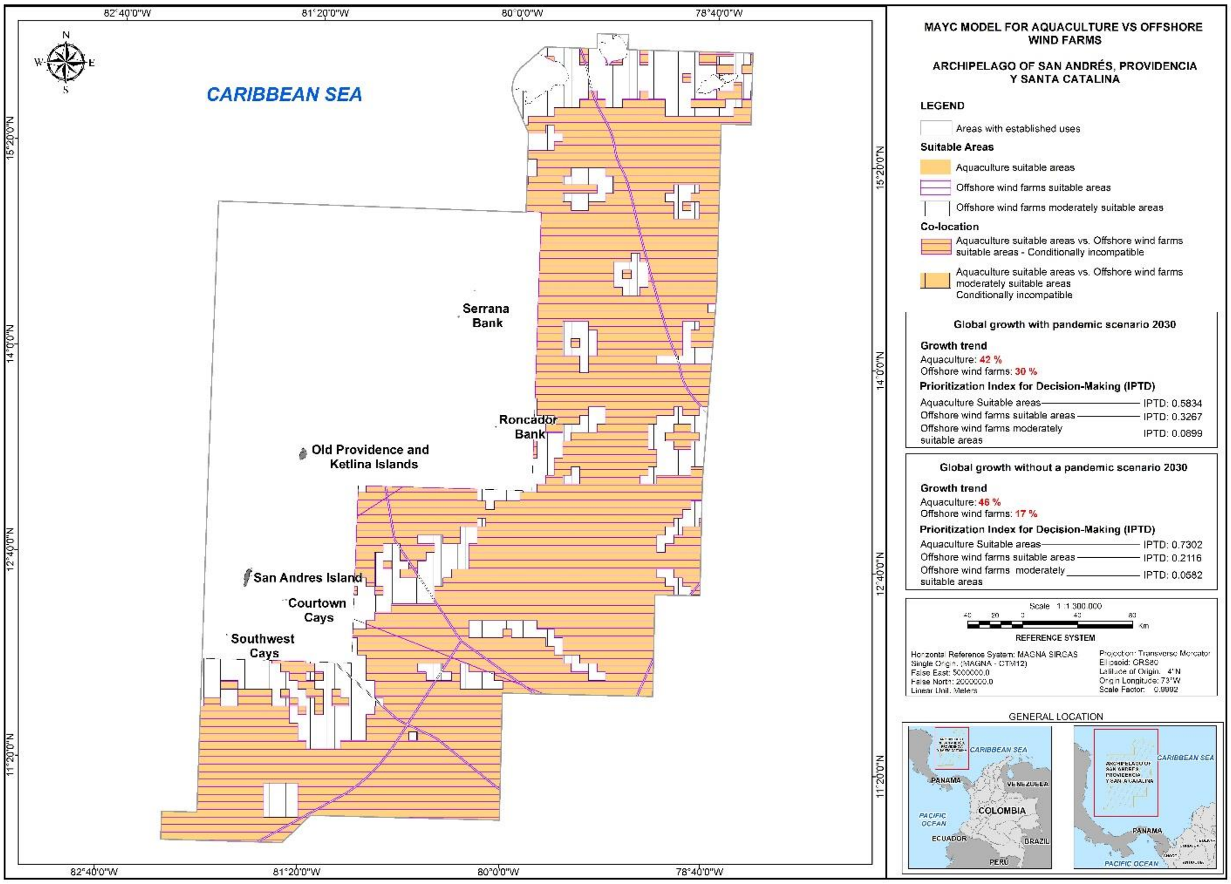

Figure 11. Map of future conditions for aquaculture and offshore wind farms in the scenario with and without pandemic of the Archipelago of San Andrés, Providencia y Santa Catalina.

Table 9. Prioritization Index for Decision-Making under non-pandemic and pandemic scenarios for aquaculture and submarine cable uses.

Scenario	Use/Activity	Growth trend (%)	Total area of the suitable areas (km²)	IPTD	IPTD Standardized
No pandemic	Aquaculture Suitable areas	46 (FAO 2016, 2020).	101663.8963	0.4597	0.9350
	Submarine cables Suitable areas	3.2 (Echeberría, 2020; Research and Markets, 2020).	80219.62134	0.0252	0.0513
	Submarine cables Moderately suitable areas	3.2 (Echeberría, 2020; Research and Markets, 2020).	21433.62719	0.0067	0.0137
With a pandemic	Aquaculture Suitable areas	42 (FAO 2020)	101663.8963	0.4197	0.8607
	Submarine cables Suitable areas	6.8 (Research and Markets, 2022; Tele-Geograp,hy 2022).	80219.62134	0.0536	0.1100
	Submarine cables Moderately suitable areas	6.8 (Research and Markets, 2022; Tele-Geography, 2022).	21433.62719	0.0143	0.0294

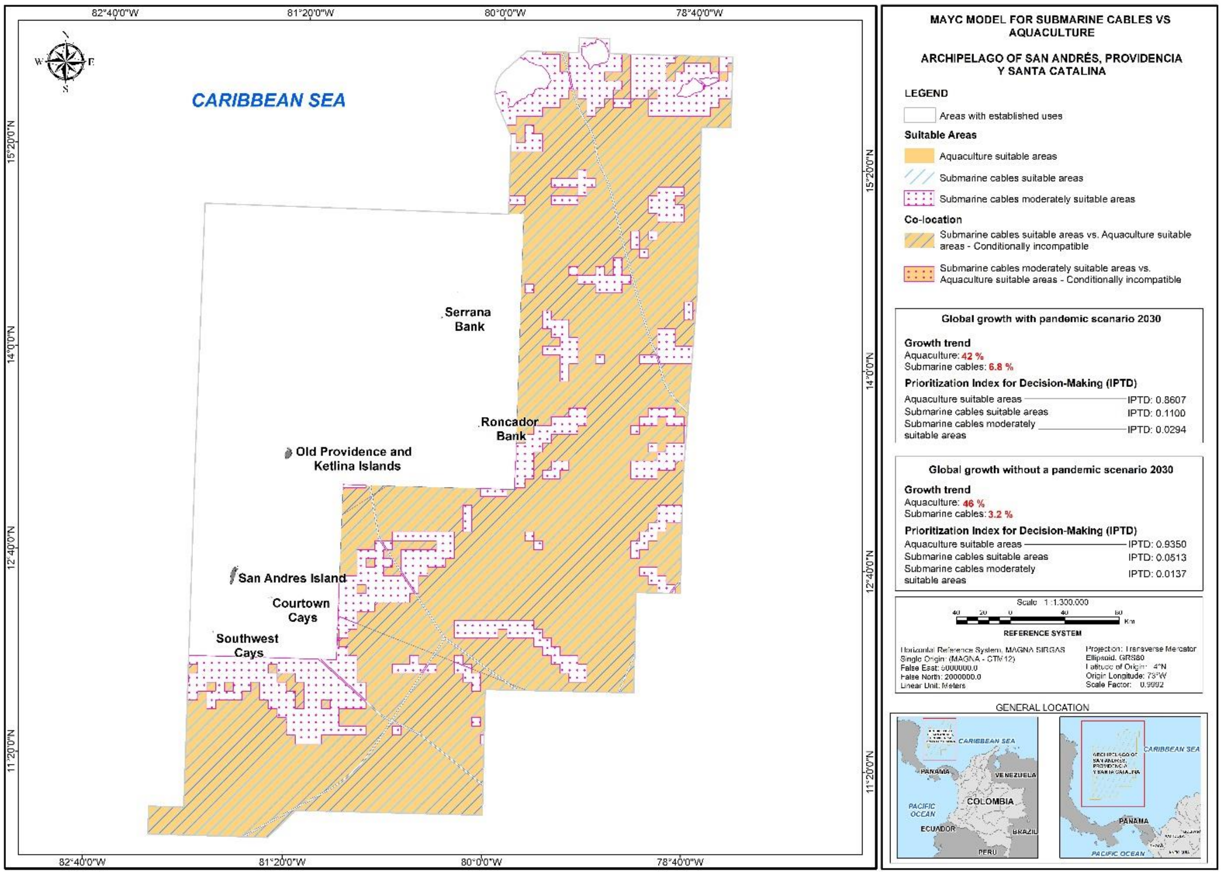

Figure 12. Map of future conditions for aquaculture and submarine cables in the scenario with and without pandemic of the Archipelago of San Andrés, Providencia y Santa Catalina.

Table 10. Prioritization Index for Decision-Making under non-pandemic and pandemic scenarios for the uses of submarine cables and offshore wind farms.

Scenario	Use/Activity	Growth trend (%)	Total area of the suitable areas (km^2)	IPTD	IPTD Standardized
No pande-mic	Submarine cables Suitable areas	3.2 (Echeberría, 2020; Research and Markets, 2020).	80219.62134	0.0252	0.1250
	Submarine cables Moderately suitable areas	3.2 (Echeberría, 2020; Research and Markets, 2020).	21433.62719	0.0067	0.0334
	Offshore wind farms, suitable areas	17 (GWEC 2019).	79717.3333	0.1332	0.6600
	Offshore wind farms, moderately suitable areas	17 (GWEC 2019).	21933.91055	0.0367	0.1816

Scenario	Use/Activity	Growth trend (%)	Total area of the suitable areas (km^2)	IPTD	IPTD Standardized
With a pandemic	Submarine cables Suitable areas	6.8 (Research and Markets, 2022; Tele-Geography, 2022).	80219.62134	0.0536	0.1458
	Submarine cables Moderately suitable areas	6.8 (Research and Markets, 2022; Tele-Geography, 2022).	21433.62719	0.0143	0.0390
	Offshore wind farms, suitable areas	30 (GWEC 2021).	79717.3333	0.2351	0.6393
	Offshore wind farms, moderately suitable areas	30	21933.91055	0.0647	0.1759

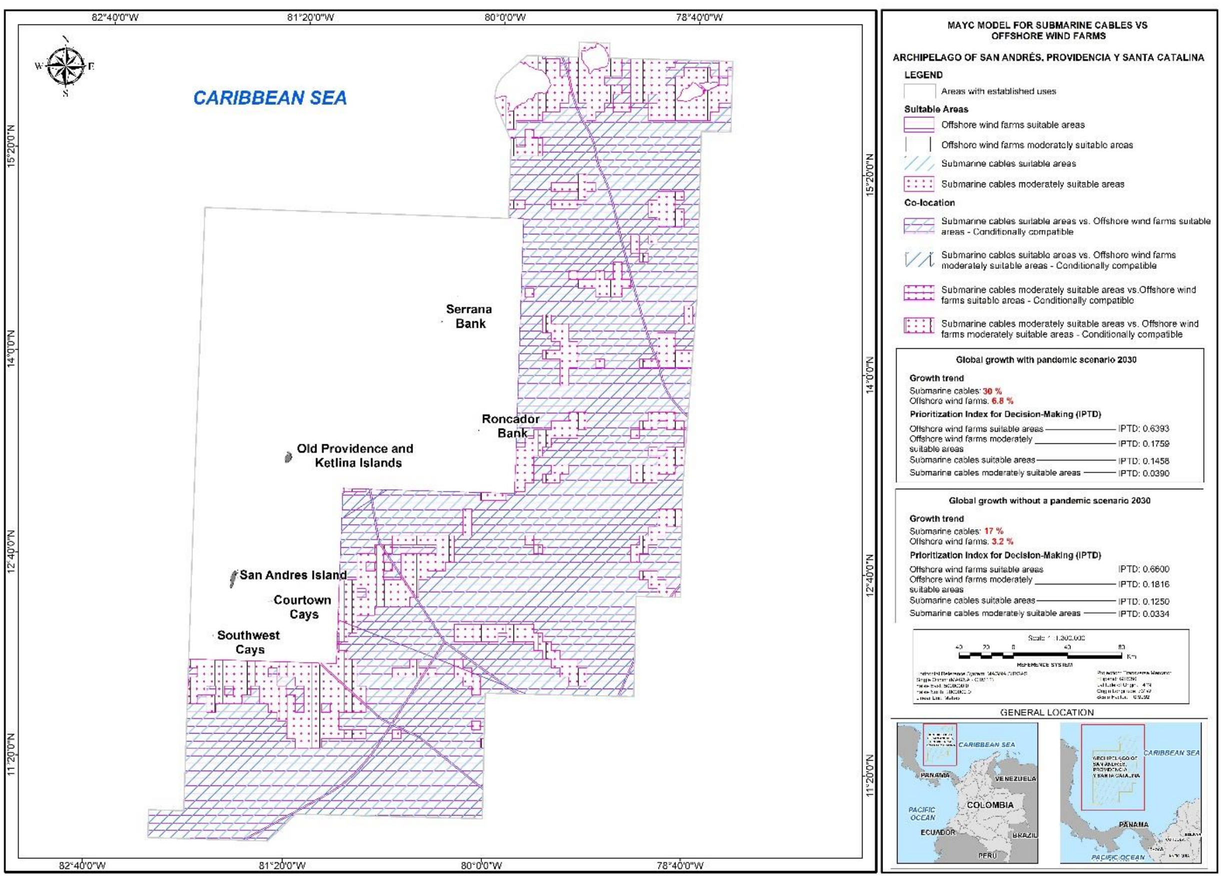

Figure 13. Map of future conditions for submarine cables and offshore wind farms in the scenario with and without a pandemic of the Archipelago of San Andrés, Providencia y Santa Catalina.

Discussion

In the last 20 years, half of the places in the world with marine-coastal areas have implemented Marine Spatial Planning as a tool for the management of these spaces, in order to seek a balance between the conservation of ecosystems and socioeconomic development. In Colombia, DIMAR has implemented its methodology based on the PEM with a quantitative approach in different geographical areas; however, it has been shown that in underdeveloped countries and small islands these processes are affected by factors such as climate change, natural disasters and, mainly, the lack of spatial information related to cultural, economic, ecological and social aspects (Ban, Hansen, Jones, & Vincent, 2009; Ehler, 2021; Mead, 2021). In addition, some island areas may have a much larger marine area than their terrestrial portion, making it difficult to manage marine resources (Jumeau, 2013).

Although progress in the PEM is limited in small islands, due to the different limitations, in some Caribbean islands such as the Dominican Republic, Saint Lucia, the Grenadines, Barbuda, Montserrat, Saint Kitts and Nevis, it has been implemented, with significant progress in the last decade (Flower *et al.,* 2019; Mahadeo, 2022; Pomeroy, Baldwin, & Mc. Conney, 2014; Caribbean Environment Program, 2019; Díaz-Romero, Domínguez-Tejo, & Schill, 2012; The Nature Conservancy, 2012). Likewise, in islands in Asia, French Polynesia and the United Kingdom, among others (André, Van Wynsberge, Chinain, Gatti, Liao, & Andréfouët, 2022; Hardman *et al.,* 2022; Sujadmi & Murtasidin, 2020), these planning instruments have been applied, thus they can become a reference for other island areas.

Globally, economic activities in island areas are mainly related to the tourism and fishing sector (André *et al.,* 2022; Flower *et al.,* 2019; Pratt, 2015). However, due to the limitations of these island spaces, the economy depends on external investments and activities that are mainly carried out in the marine space (André *et al.,* 2022; Flower *et al.,* 2019; Greenhill & Pro, 2018; Pratt, 2015). The Archipelago of San Andrés, Providencia y Santa Catalina is no exception, because it is considered one of the main tourist destinations in Colombia and its economy revolves around this activity, as well as fishing and trade (Aguilera-Díaz, 2016).

Additionally, part of the maritime territory of the Archipelago is protected under the figures of 'marine protected area', 'national natural park' and 'regional national park', with a wide variety of ecosystems that provide services such as food, recreation, coastal protection, among others. However, according to the analysis of the MCM:MAV, it was identified that these areas present a high degree of conflict with uses such as artisanal fishing, beaches with a tourist vocation, landfills, dredging and oceanic engineering works, due to the fact that their regulations limit the development of these activities (Coralina, 2018; Sánchez, 2012).

Despite the maritime activities that are currently being carried out in San Andrés, Providencia y Santa Catalina, one of the challenges of MCM:MAV is to identify the potential for new uses/activities and to establish whether the physical and environmental characteristics of the marine area are adequate for its operation (Afanador-Franco *et al.,* 2022, 2023), contributing to the diversification of the economy and the improvement of the conditions of the population.

Taking into account the above, activities such as aquaculture, wind farms and submarine cables have a high growth trend in the horizon of 2030, due to their importance in terms of food security, clean energy generation and the provision of telecommunications services (Communications Regulation Commission, 2020; Echeberría, 2020; FAO, 2016, 2020; GWEC, 2019, 2021; Research and Markets, 2020, 2022; TeleGeography, 2022). Aquaculture projects are not carried out in the Archipelago (Merino, Bonilla, & Bages, 2013); however, according to Hortúa (2013) and the results corresponding to the suitable areas obtained in this study, it is considered that the area has a high potential for development. Still, it is likely that the current regulations, the lack of research and investment, both from the private and public sectors, added to the costs of transportation, construction, and operation, have not allowed the execution of this activity in these islands (Decree No. 2668 of 2012, Government Department of the Archipelago of San Andrés, Providencia and Santa Catalina, 2020; Greenhill

& Pro, 2018; Merino *et al.,* 2013; Sarmiento-Guerrero, Pérez-Walteros, 2021).

With respect to offshore wind farms, in Colombia, it was only until 2022 that the guidelines for the allocation of areas in the departments of Bolívar and Atlántico were established (Resolution No. 40284 of 2022). Therefore, these types of projects do not exist yet. In the Archipelago, the energy supply has total coverage, but it depends mainly on fossil fuels that produce high air pollution (approximately 134 thousand tons of CO_2 per year). The Archipelago has been making efforts towards the generation of clean energy. Proof of this is the result of this study, which indicates that there is an area of 79,717.33 km^2 of suitable areas (physical and environmental conditions) that correspond to 48.02% of the total area. The studies also point to the potential of wind energy in San Andrés, identifying a possible saving of 8% of the CO_2 emissions currently emitted by the island (IDB, 2016; Grueso-López, 2022).

Likewise, studies have been carried out for the use of wind and solar resources coordinated by the National Learning Service (SENA), highlighting a wind energy proposal that is in the technical feasibility stage (Matiz-Chicacausa *et al.,* 2016; SENA, 2013). However, the construction of these large-scale projects in isolated areas could have very high costs that make their execution difficult (IDB, 2016; Gómez, 2022).

As for submarine cables, before 2020 the Archipelago had only one (San Andrés Isla Tolú Submarine Cable - SAIT), and there were connectivity problems, mainly associated with network saturation and limiting characteristics for the installation of new cables such as geographical location, high infrastructure and transport costs (Martínez, 2017; MinTIC, 2020); however, since 2020, after Hurricane IOTA hit the area, a new submarine cable (America Móvil Submarine Cable System-1, AMX-1) was installed. This generated an advance in telecommunications, increasing the national and international connection that positions it as the second fastest in the country (El Tiempo, 2023). Although the installation of more cables is not planned in the short term, according to the results of the MCM:MAV, the area has 80,219.62 km^2 of areas that meet the physical and environmental conditions for the laying of new submarine cables, which correspond to 48.32% of the Archipelago.

In addition to identifying the activities with the greatest growth potential in the scenarios proposed by Dimar, the MCM:MAV makes it possible to define whether they can be developed in the same geographical space and to establish whether the development of one affects the other, taking into account a co-location analysis, which determines the compatibility/incompatibility between them (Afanador-Franco *et al.,* 2022, 2023). In island areas that have less accessibility due to their geographical location, limited public services, poor food security, among others, the development of large-scale maritime activities can generate high costs, which can limit investment by both the public and private sectors, affecting the quality of life of the population (André *et al.,* 2022; Gómez, 2022; Universidad Distrital "Francisco José de Caldas", 2020). Therefore, it is important to properly manage these spaces, in such a way that it is possible to identify which uses/activities can be more efficient and effective in the same area (Afanador-Franco *et al.,* 2022, 2023).

For the Archipelago, it was identified that aquaculture projects cannot be developed with submarine cables or offshore wind farms, mainly due to the accidental damage that may occur (Afanador-Franco *et al.,* 2022, 2023; Cardia *et al.*, 2017; Meindl, 1996; Queensland Government, 2019; Rojo, 2016). While wind farms, being conditionally compatible with submarine cables, could be executed under certain agreements between the interested parties, since there are common interests such as safety, access, and installation, maintenance, and operations processes on the seabed, their restrictions must be taken into account (Afanador-Franco *et al.,* 2022, 2023; European Commission, n.d.; ESCA, 2016; ICPC, 2013). Additionally, in the event that applications are submitted for these three activities in the same area, according to the value of the IPTD proposed by Dimar, aquaculture should be prioritized with respect to the other two, as it has a greater growth trend and an area suitable for its operation (Afanador-Franco, Molina-Jiménez, Pusquin-Ospina, Barrientos, Banda-Lepesquer and Castro-Mercado, 2023).

Finally, as it is a continuous process and adaptable to the conditions of marine-coastal spaces, the challenge of MCM:MAV is to include climate change in future development scenarios by 2050 in the national territory, recognizing its importance and effects on the planning of maritime activities and natural resources (ECLAC, 2019).

Conclusions

The MCM:MAV is a contribution of DIMAR to the management of marine-coastal activities that take place in the Archipelago of San Andrés, Providencia y Santa Catalina, since their current and future conditions were analyzed, evidencing conflicts, compatibilities and suitable areas for the establishment of new activities.

In the Archipelago area, in the cross-matrix of compensation by pairs, a total of 1,444 crossings were analyzed among the 38 identified uses/activities, of which 288 correspond to areas where there is overlap with conflicts, 180 are areas of overlapping uses, but without conflict, and 976 areas with no overlap between uses/activities.

Likewise, through zoning by conflict index, areas with high, medium and low levels of conflicts were established, depending on the weights assigned from the normalized matrix of compensation by pairs. This indicates that the maritime uses/activities with the highest rate of conflict correspond to restricted areas, marine protected areas, artisanal fishing areas, beaches with a tourist vocation, and corals.

The maritime activities with the most conflicts identified from the overlaps for the Archipelago of San Andrés, Providencia y Santa Catalina correspond to artisanal fishing zones, restricted areas, marine protected areas, seagrasses, and corals.

The application of the MAYC methodology was carried out in the areas free of uses/activities, which represent 61.24 % of the study area, identifying the areas suitable for aquaculture (61.24 %), wind farms (48.02 %), and submarine cables (48.32 %).

The Co-location model made it possible to establish that in areas where aquaculture uses/activities overlap *vs.* wind farms or submarine cables, only one of the two can be developed. Additionally, in cases where proposals for submarine cables with wind farms are submitted and overlap, the interested parties must reach agreements to execute their projects with the minimum number of conflicts.

The IPTD in the two future development scenarios for the Archipelago of San Andrés, Providencia y Santa Catalina suggests that the use of aquaculture should be prioritized over wind farms and submarine cables, due to the fact that it has a greater growth trend.

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