Colombian Caribbean marine biodiversity mapping for conservation planning

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by

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ABSTRACT

Perturbations resulting from human activity in marine systems have resulted in habitat change and species lost. As such perturbations may reduce diversity in marine environments, site conservation networks are increasingly seen as refuges for conserving biodiversity. Because all the marine areas contain biodiversity, but not all of them can be targeted for action a selection of sites have to be accomplished. An adequate way of mapping, measuring and analysing marine biodiversity supporting different stakeholders' priorities and interests identifying potential conservation areas in the Continental Caribbean coast of Colombia is the focus of this study. Due to the impossibility to map biodiversity as such, macrobenthic species assemblages, benthic habitats and ecoregions are used as surrogates for biodiversity. Three main phases are identified in the research: A *Data management* phase, in which a selection of the available sources of biodiversity information for the Caribbean Colombian slope was made. The *biodiversity assessment* phase deals with the measurement of biodiversity itself throughout classical community analysis and the mapping of macrobenthic species assemblages predicted distribution. The final phase *Site identification* deals with the selection of representative sites or planning units accounting for the conservation targets. This selection is based solely on specific biological and environmental conservation features. Cluster and ordination analysis based on presence/absence macrobenthic species showed a clear separation of nine species assemblages regulated by depth and ecorregions distribution. Three classified data layers became the proxy for conservation features in the site selection: benthic habitats (coral reefs and sea grasses), ecoregions and nine macrobenthic species assemblages' distribution. Eleven solution were produced in the MARXAN software searching for the two best comprehensive representations of the conservation features within the available planning units. The best solution over two scenarios: the "*No reserve*" and "*Seed PU*" were selected. For both scenarios, 4895 planning units and 20 conservation features were used. Based solely on biological criterion the southern region of Islas del Rosario National Park, Santa Marta and Guajira regions were consistently selected as a representative sites of biodiversity. The study advocate a systematic and objective framework to site selection based solely on biodiversity contents in a regional scheme template.

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1. Introduction

The term Biodiversity has been defined by many authors [1-5] but in general terms can be understood as the *variety of life*. According to Sarkar and Margules (2002) this concept includes "the entire biological hierarchy from molecules to ecosystems, or the entire taxonomic hierarchy from alleles to kingdoms, all the logical classes in between (individuals, genotypes, populations, species, etc.), and all of the different members of all those classes. It also includes the diversity of living interactions and processes at all these levels of organization". Such definition could become an intimidating idea when trying to outline the actions needed to conserve marine biodiversity from degradation and extinction and moreover from local initiatives up to national or even global enterprises. [6]

Perturbations resulting from human activity in marine systems have resulted in habitat change and species lost. As such perturbations may reduce diversity in marine environments, site conservation networks are increasingly seen as refuges for conserving biodiversity [1, 7-11]. Planning and designing these networks are based on representativeness principles as a mayor selection criterion. Representativeness in this case, means the desire of planners to incorporate samples of each ecosystem, habitat, assemblage, community type or specie, depending on the scale of the marine area to be addressed (ranging from continental 1000 km to site 1 km [12]) and the intended conservation effort. Because all the marine areas contain biodiversity, but not all of them can be targeted for action, first a selection of sites and then a prioritisation have to be accomplished [1, 7]. From the perspective of nature conservation these actions would attempted to comprise the largest possible network; however, in reality the extent on any conservation system will be limited by social and economical constrain [2].

> *"To meet the objective of identifying and mapping priority areas, there must be an acceptable way of measuring biological diversity, a way of determining an acceptable level of representation of that diversity in conservation areas (i.e. setting the goal) and having set that goal, a cost-effective way of allocating limited resources to secure it" [5].*

A comprehensive cataloguing of biological diversity and the study of species distribution patterns in relation to the environmental, biotic and anthropogenic factors is then a prerequisite for site selection [13]. Accurate mapping at a scale at which conservation network sites are designated and managed, is essential to measure and consider biodiversity representation [1, 12]. Extensively and densely sampled areas, such as the Gulf of Maine, relay on *Biogeographic Information System* (GMBIS) to facilitate the characterization of biological distributional patterns within the region. This System allows the understanding of marine population distribution and dynamics in terms of bio-physical process, operative over multiple spatio-temporal scales and interespecific habitat and fisheries interactions [13]. Although such system is the ideal decision support tool for promoting the integrated approaches to natural resources management, ironically, most of the considered *hot spots* for marine biodiversity around the world, lack on the information or resources to obtain such a comprehensive inventories.

Global initiatives, such as the Census of Marine Life (CoML) aiming to document what lives on the ocean, so changes can be monitored and understood, stumble upon the lack of adequate biodiversity distribution information. This situation can be understood by considering the little research efforts focusing on the marine environment, resulting in less than 0.1 % of the volume of the ocean being sampled [14].

This estimation is clearly comparable to the actual knowledge on the distribution of the marine biodiversity along the national submerged territory of Colombia that attains for 50% of the total. In the global context, Colombia is recognized as a country with a high biological terrestrial diversity, since it possesses near 10% of the world's terrestrial diversity whilst occupying only 0.7% of the world's surface [6]. The importance of biodiversity as well as the adoption of measures for its conservation, sustainable use and distribution of outcome benefits are reflected by the ratification of Colombia to the global *Convention on Biological Diversity* in 1994 [15]. Traditional communities have long used biodiversity as direct or indirect base of numerous productive activities and thus play a strategic role in national development and future prospects for its sustainable use [15].

On similar initiatives towards the management of marine biodiversity, the *Environmental National Policy for the sustainable development of the oceanic space and coastal and insular zones of Colombia* [16], establishes a general and long-term frame to direct *three* national strategies on this topic: conservation, knowledge and sustainable use of marine and coastal biodiversity.

The *conservation* strategy includes the reduction of processes and activities that cause loss or damage to biodiversity, the recuperation of degraded ecosystems and threatened species and the establishment and management of a network system of protected areas. This system includes 12 coastal and marine protected areas (from a total of 49), being 4 of them located on the continental Caribbean covering an area of approximately 2.100 km^2 from the total [17]. The *knowledge* strategy involves the characterization of elements of biodiversity at the ecosystem, population, species and genetic level; and the recuperation of traditional knowledge and practices. The *sustainable use* strategy seeks to incentive the use of sustainable management systems, the establishment of biotechnology programs, the design and implementation of biodiversity multi-criteria valuation systems and mechanisms for an equal distribution of the benefits derived of its use. It also includes measures to promote the sustainable use of the economic potential of biodiversity [15].

These three strategies shared the common need of comprehensive, accurate and efficient mechanisms to fill or complement the information required to support participatory decision making processes, concerning the conservation of marine biodiversity entities. Managers, scientists, decision makers and researchers need satisfactory biodiversity information in order to make reasonable, justifiable and concerted decisions [4]. Ecological, taxonomic, social and cultural variables require corresponding information scales for the assessment of biological diversity [9].

Up to date in Colombia there has been few attempts to generate effective mechanisms supporting distribution assessments of marine biodiversity, capable of describing current and past environmental baseline conditions in order to guide management decisions, monitoring initiatives and modelling of alternative conservation policy effects. The use of already available information (e.g. grey literature and related former project results) and expert opinion backed up maps of appropriate marine biodiversity surrogates could be seen as a starting point for the fulfilment of this common need. Using existing data and identifying their limitations for conservation planning, will certainly trigger overall data needs recognition to meet marine biodiversity conservation goals.

Due to the impossibility to map biodiversity as such (genes, species and ecosystems) [1] the use of biodiversity surrogates [5] need to be further explored. Some biodiversity surrogates encountered in literature include several diversity indexes [3], species richness [6], or presence [8], habitat diversity [11, 18, 19] (geomorphologic structure and benthic cover) [10], bio-geographical patterns [13], abiotic datasets [12], food webs, macrobenthic communities [14], patterns of connectivity [20], species patterns and environmental gradients [21], and higher taxon distributions [7]. Gerner and Bryan (2003) even used a hole set of surrogate data to identify unique environmental classes including bathymetry, sea surface temperature, chlorophyll ‘a’ concentration levels, benthic habitats, a regional coverage of bio-units and use it to systematically plan marine protected areas (MPA) in the Encounter Region of South Australia’s waters.

Nevertheless, no highly preferred surrogate features (sub-sets of taxa, assemblages, and/or environments and environmental variables) have proven to be universally applicable to aid the selection or prioritization of network sites for biodiversity conservation [1, 5, 9]. Representation of endemic, rare and migratory species are also important, as well as high productivity, spawning, nursery and feeding grounds; Areas important for these reasons are generally not included in the selection of networks based solely on taxon diversity basis [7], and therefore especial attention must be paid to complementary sources of information (i.e. existing endangered species).

Multiple users requiring information for biodiversity conservation should be able to acquire it on the context within which and the issues on which they need to focus. The role that Geographical Information System (GIS) is playing as integrator of all these forms of data are of great importance and its applications for assessment and monitoring purposes are becoming unlimited [11, 13, 18, 19, 22-24], moreover when dealing with incomplete sets of information [4, 8, 25]. The need to find more effective mechanism to support present and future attempts in marine conservation planning had trigger several approaches in the Caribbean Colombian region including the one described herein.

So far, the efforts for the conservation in situ of the natural marine patrimony of the country have been insufficient and lack of adequate mechanisms that guarantee the accomplishment of its objectives. Despite having undertaken a commitment to the Biodiversity Convention, there is very little in the way of detailed information regarding impacts on coastal and marine ecosystems. Indeed, there is little information at all on the status of the coastal and marine ecosystems except in very localized areas, which have been subject of recent study. In Colombia, ecological research for coastal and marine areas is poor and there is an almost total lack of data on which to base conservation or management strategies. No particular criteria at all are defined for the establishment of marine protected areas. Consequently these areas cannot be evaluated with respect to the degree to which they fulfil their conservation and management objectives.

The identification and mapping of defined surrogates for marine species biodiversity[1] serving the purpose of being one of the multiple criteria needed for the delimitation of potential conservation reserve sites is the main goal intended by the present study. The assessment of the spatial dimension

[1] Otherwise specified the term biodiversity is considered at species level (not genes or ecosystem entities [1]) using the macrobenthic community as the main descriptor.

in which this information could be stored and/or extracted, exploring the use of different GIS's applications, was also aimed. It's expected that follow up research initiatives incorporate economic, social and more detailed and wider range bio-geographical information not taken into account in the present study, supplying more realistic recommendations in current and future reserve site selection processes replacing *ad-hoc* approaches used out until now.

1.1. Research problem

The main problem that triggered the research was the need to generate an adequate way of mapping, measuring and analysing marine biodiversity supporting different stakeholders' priorities and interests in the assignment of identifying potential conservation areas. The use of existing information allows the estimation of the sufficiency of the present initiatives into collecting new information to met marine conservation data needs. An unified spatial tool to incorporate this information as well as other sources of similar nature is lacking as far as known.

1.2. Research objectives

The general objective of the research was to assess the use of specific surrogates along the Caribbean continental slope of Colombia to represent marine biodiversity in order to determine it's convenience as a criterion supporting biodiversity conservation planning process. In order to achieve this general objective, the accomplishment of the following specific objectives was proposed:

1. Describe the spatial distribution of marine biodiversity through already available bio-geographical information using biodiversity indexes, macrobenthic species assemblages, benthic habitats and ecoregions as surrogates.
2. Assess the effectiveness and convenience of the use of the resulting spatial representations as a complementary tool in the current and used procedures to prioritise biodiversity conservation sites.

1.3. Conceptual framework

Three main phases can be identified within the research: Data management, biodiversity assessment and site identification (Figure 1).

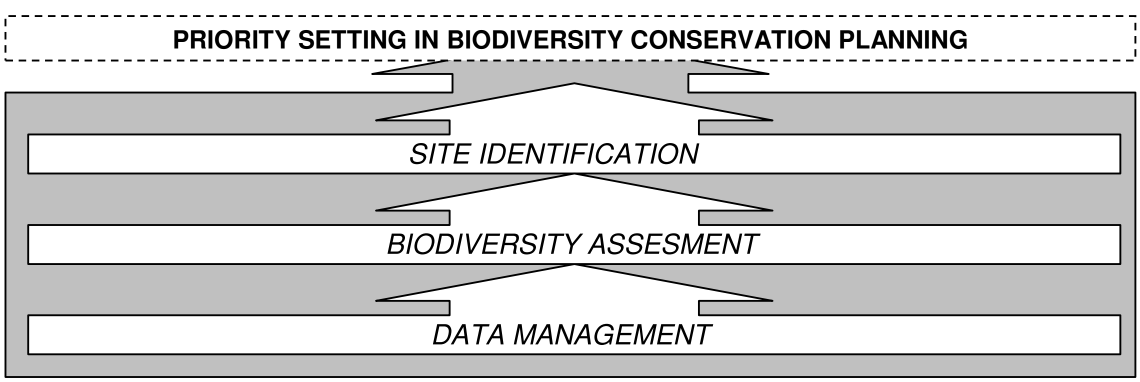


Figure 1. Conceptual framework of the research

Throughout the first phase, the *Data management*, a selection of the available sources of biodiversity information for the Caribbean Colombian slope was made; only available datasets that had associated a trustful geographic reference were considered for analysis. The *biodiversity assessment* phase deals with the measurement of biodiversity itself, the selection of appropriated surrogates and the analysis of how this information can be mapped to give a comprehensive representation of the information available. The final phase *Site identification* deals with the identification of representative sites or planning units from which to select representative targeting conservation features. This selection is based solely on specific biological and environmental conservation feature goals.

1.4. Research questions

Following the described conceptual approach, the following research questions were formulated.

1. What is the spatial dimension (spatial coverage and spatial resolution) of macrobenthic species in the Colombian Caribbean region?
    - How can spatial structure analysis improve the results of predicting species distribution in comparison to the use of classical community analysis (classification and ordination techniques) ?
2. Which of the biodiversity surrogates can be accounted as conservation features for the selection of potential conservation sites?
    - How this approach could be the implemented to support Colombian marine biodiversity conservation planning process?

1.5. Scope and assumptions

The scope of mapping marine biodiversity is very broad and it is very unlikely that a single approach will capture all of its intended referents. However, this research aim to be a general insight into the different efforts that could follow future research in targeting places for protection. More emphasis should be given to asses the precision needed to target places for protection that were not specifically measured in this effort.

In general terms it's already known the location of the main marine and coastal ecosystems of the Caribbean coast of Colombia as well as the species that are threatened by extinction. However, no explicit spatial representation can show where they are found in an integrated matter. This result alone can be considered as an important progress to the current initiatives towards biodiversity conservation.

An identification of sites representing biodiversity surrogates and not a prioritisation of these areas is assessed by this approach. Biodiversity as such must only be seen as one of the multiple criteria needed to define areas for conservation. Some other entities such as limiting social, economical and administrative constrains are needed to be considered in the process.

This research was developed using available information and thus was subject to multiple sources of error such as misleading species identification, ambiguous synonymies, and inaccurate spatial descriptors. Nevertheless, is meant that all these considerations are taken into account when discussing the findings of the research.

2. Methods

The research method followed by this study link to the first stages of the *Framework for Systematic Conservation Planning* proposed by Margules and Pressey (2000) except that it uses strictly biological and environmental conservation features for the selection of sites. This Framework offers a quantitative and replicable way to plan reserve systems and includes principles such as representativeness, adequacy, efficiency and others over a predefined region. These principles are then implemented in computer models to provide on-ground prescriptions for reserve design [24].

The nature of this mathematical approach requires a clear statement of the conservation objective in order to inform how the site selection will proceed. According to the principles of systematic conservation planning [5] explicit targets for biodiversity features should be specified as a way of involving and measuring more general conservation goals [26]. In this study the goal is to identify marine sites referred as *planning uni*ts in the optimization model, that are as representative of biodiversity as possible; that is, they should encompass all the biodiversity surrogates in the data set.

The representativeness principle concurs with the general target of *in situ* conservation purpose of Colombia. This target aims to represent the ecosystem, landscape, and biotic diversity of the national territory under the national protected areas network known as SINAP (Sistema Nacional de Áreas Protegidas) [27]. There are 49 protected areas in the SINAP, covering approximately 9.200.000 Ha (8.5 % of the national land territory). From this total, eleven have boundaries extending over a submerged portion on the Caribbean and Pacific coasts and four are located at the continental Caribbean coast, focus of this research.

2.1. Study area

Colombia is the fourth-largest country in South America and the only one with coasts on both the Pacific Ocean and Caribbean Sea. Jurisdictional waters cover almost 50% of the total area. The continental platform along the 1,642 km of the Caribbean coastal line [28] up to 600 m depth, is the target area for this research (Figure 2). It has a maximum width of 25 km and minimal of 6 km (in front of the Sierra Nevada de Santa Marta). The limit between the platform and the continental slope is around 30 m depth [29]. It is influenced by a considerable amount of fluvial contributions (15.430 m^3/s) from the Sierra Nevada de Santa Marta, the Magdalena, Atrato and Sinú rivers, all of them causing silt distribution material exchanging the dynamics of physical processes [30].

Three mayor sectors can be identified along the coast based on the sedimentary properties of the continental platform (Appendix 2). The first one, running from the south from the Uraba Gulf up to the Sinu River, seemed to be invaded by sedimentary detritus subjected to the seasonal variation of this highly hydrodynamic sector. The sedimentation from this sector appears dominated by silt and silty sand towards the south in the entrance of the Uraba Gulf. Towards the north the former reef complexes sect influences the presence of mixed carbonated and clastic deposits between 80 and 90 m deep [31].

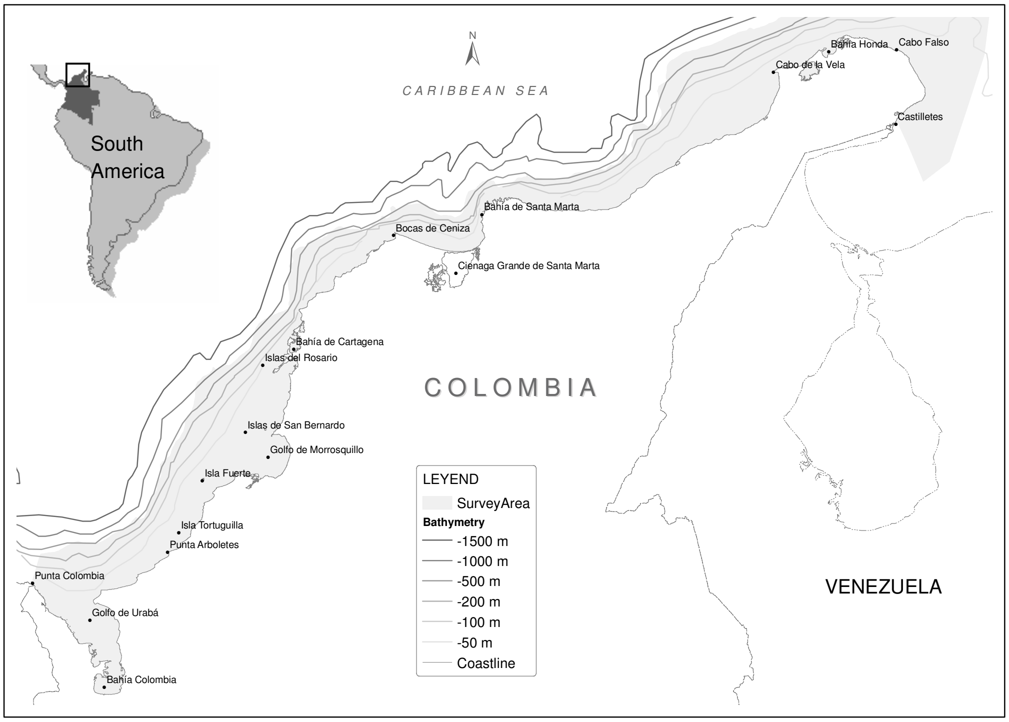


Figure 2. Map showing the study area on the Caribbean region of Colombia.

The second sector running north up to the Santa Marta region (Appendix 2) is relatively narrow and shallow especially in front of the Magdalena River mouth (12 m). This sector is dominated by six main sedimentary facies, four of them from terrigenous origin occupying 96% of the area. The remaining 4 % correspond to carbonated sediments with lithobioclastic and bioclastic sands. The distribution of facies is dependant of the presence of the Magdalena canyon, the river discharges and the sea currents repartition, reliant on the yearly season [32].

Based on its morphological characteristics the north and third sector could be divided in two different areas. East of Cabo de la Vela (Appendix 2) where the platform is very narrow (maximum 15 km) with a general concave profile and from Cabo de la Vela downwards where platform widens up to 40 km with 0.2 % slope. Sea currents dominate the sedimentary repartition on this sector. It lacks from great river discharges minimizing the influence of terrigenous depositions. Western the Cabo de la Vela coarse white sands composed by calcareous algae dominate the area. Eastern to this point, the sediments appear siltier with the absence of pure sand [31].

The semi-enclosed sea above the continental platform has almost a stable thermo cline (close to 15°C between 100-200m) through the entire year, perturbed only by winds and currents favoring the up-welling phenomena from 180 to 200 m deep [33] occurring at the Guajira peninsula and Magdalena department. This favourable and highly productive environment condition provides sufficient biological support for a dynamic fisheries industry [34]. Tides regime are either mixed semi-diurnal or mixed diurnal being the greater amplitude 0.5 m [35].

The warm and relatively shallow waters allow the settlement of complex environments, holding numerous species and endemism [36]. Seven ecosystems are well represented along the coast: rocky shores, sandy beaches, lagoons and estuaries [28], mangroves [37], sea grasses [38], coral reefs [39] and mud sea beds. This last ecosystem covers just about 95 % of the total area of the continental platform [40] and is the one holding the fauna assessed by this research.

The Colombian Caribbean region between 150 and 400 m depth holds around 700 different macrobenthic species among the mayor taxa. This estimation responds to the benthic fauna inventories carried out just in recent years. By the year 2000 the presence of almost 300 species were registered for the first time in this area and the description of 15 new species to science including one new genus and one new subgenus were recorded [41].

In general terms the knowledge on the marine biodiversity of Colombia is rather scarce; It's estimated that knowledge regarding the number of species based on existing inventories is as low as 30% in comparison with the presumed number that could be expected from a tropical country with coastline on both oceans [41]. This last statement then again proves the need for efficient and useful tools, to support conservation planning process making possible the management of such complex biodiversity.

Compiling a data set for conservation planning, is a process that includes both acquiring relevant data and, in most cases, analysing those data (classification, ordination, and/or mapping) so that they are in a form suitable for identifying biodiversity priority areas. The implementation of these steps is address in the following section in accordance to the conceptual framework of the research.

2.2. Data management

The first task of any systematic biodiversity conservation planning process [42] is the selection of appropriated surrogates that represent the target of conservation. This process assumes that bio-geographical and other data on which conservation decisions must be made have already been collected. Two main sources of data were used in this study to serve as a basis for the selection of biodiversity surrogates: Data points representing macrobenthic species records and coverage maps representing ecological and environmental variables.

2.2.1. Macrobenthic species

Within the frame of the Marine and Coastal Biodiversity National Research Program of Colombia PNIBM 2001-2010 a participative and concerted approach, resulted with the delimitation of nine natural "ecoregions" along the three coastal areas of the country. The resulting zoning aimed to facilitate the articulation processes within local and regional stakeholders in the marine biodiversity research and planning actions contemplated in the PNIBM. This delimitation also aimed to organize the storage and retrieval of secondary sources of information [43].

Following this line of action, an attempt to characterize and generate a complete inventory of the macrobenthic community of soft bottom species from each of the eco-regions have been carried on by a group of scientist at the Marine and Coastal Research Institute of Colombia- INVEMAR [41].

The first tangible result of this initiative is a macrobenthic species inventory from 39 sampling points between 150 and 450 m depth along the Caribbean platform completed by May 2000. A second survey of the platform between 20 and 500 m along 41 stations complemented the previous inventory throughout the year 2002. A compilation of 1210 species from mayor taxa was obtained.

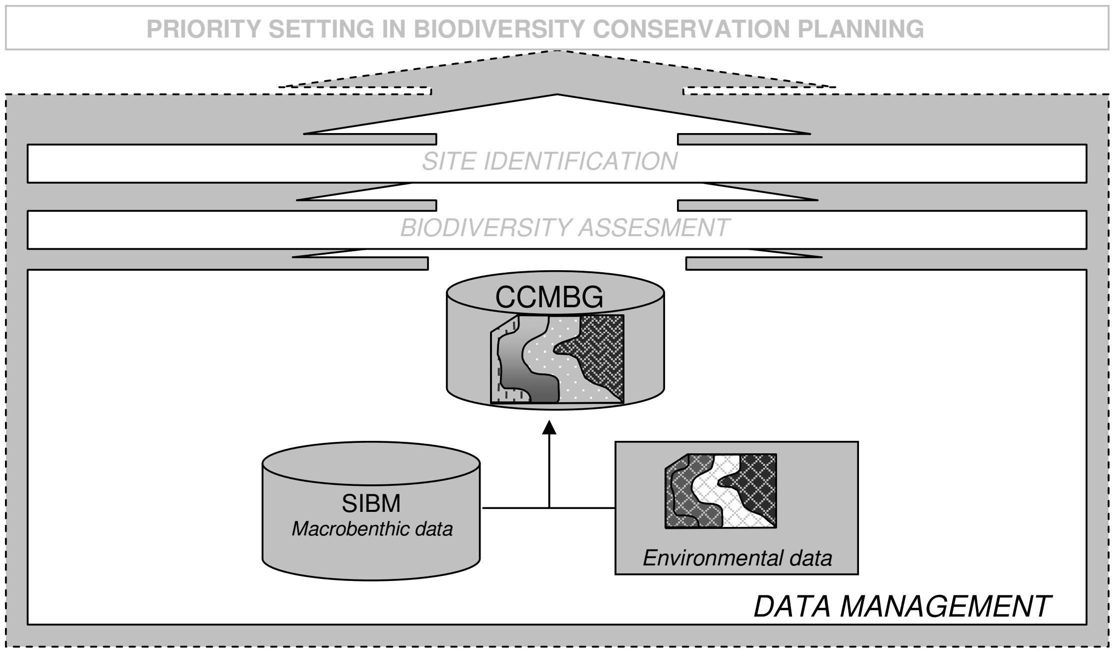


Figure 3. Research framework for the data management phase.

The data from this inventories as well as previous organism records are stored into a database management system known as SIBM (from the Spanish acronym of Marine Biodiversity Information System). This database runs under ORACLE environment and contains information on collection sites, taxa descriptions, identification guides, references, technical glossary and taxa specialist contacts. It is actually under the management of INVEMAR (www.invemar.org.co).

The term "benthos" divided bottom associated organisms into three size groups. Microbenthos are the single celled animals, macrobenthos are animals large enough to be retained on a screen with mesh size of 1 or 0.5 mm and meiobenthos, an ill defined group of a size between these two [44]. Worms, shells, shrimps and other crustaceans are the most common animals in the macrobenthos. Many of these animals are important food sources for fish and birds and thus their importance to be studied and used for conservation purposes. Besides the facility of macrobenthos sampling over fishes and birds, many of the benthic animals have restricted mobility allowing their analysis in almost a two-dimensional scale.

2.2.2. Environmental data

A series of quantitative and qualitative, spatially reference data on generalized environmental conditions from the continental Caribbean area of Colombia was obtained from the *GIS Laboratory* at INVEMAR. Colombian marine and coastal ecosystems such as coral reef and sea grass areas as well as other environmental features where obtained in ARCGIS9.0 coverage format. Their description can be seen in Table 1. An additional subset delineating the geologic provinces of the Caribbean region was also used [45].

To structure, assemble, manage, store, and query the different types of previously described datasets a geodatabase data structure was developed using the ArcGIS Marine Data Model (MDM) as a template [46]. An advantage of using this data model is that allows to take advantage of the advance manipulation and analysis capabilities of ArcGIS, particularly the ability to capture the behaviour of real-world objects and that supports more complex rules that can be built into the geodatabase [47].

This database, called now onwards CCMBG include spatial as well as aspatial data such as species presence tables allowing mapping independent species records to show where they occur. These maps provide information on biological diversity within the region for mayor range taxa and additionally offer basic information on species ecology. By organizing the information into a the CCMBG, the analysis was not constrained by single environmental factors for which the data was available, but allowed to represent as many features as possible within the marine system complexity.

Table 1. Summary of archived digital data from the Colombian continental Caribbean maintained by the GIS Lab- INVEMAR. Selected subsets supported the research.

Theme	*Description*	*Type of object*	*Source*
Territorial sea	Area of sea adjoining the shores of the Colombian Caribbean	Area	Mapa Oficial Colombia – IGAC, 1998
Departments	Mayor administrative divisions	Area	Dma - ESRI, 1993
Municipalities	Minor administrative divisions	Area	Marco Geoestadístico Nacional – DANE 2000.
Urban areas	Limits of populated areas	Area	Marco Geoestadístico Nacional – DANE 2000.
Landscape	Coverage, land use, and biomes based on terrestrial geomorphologic units.	Area	INVEMAR, 2001
Coastal line	Traced from satellite imagines 2000	Line	INVEMAR, 2001
Rivers	Main discharge rivers on the Caribbean	Line	Dma - ESRI, 1993
Bathymetry	Linear representation of depth	Line	Dma - ESRI, 1993
National Natural Parks	National natural park system areas	Area	Áreas del Sistemas de Parques Nacionales - UAESPNN, 2000
Environmental Coastal Units	Environmental zoning.	Area	Minambiente, 2001
Ecoregions	Natural marine landscape	Area	INVEMAR, 2000
Marine sedimentary fascies	Sedimentary formations	Area	Cartas sedimentologicas – CIOH, 1990
Marine coastal ecosystems	Punctual representation of coral reefs, mangroves, sea grasses and beaches.	Point	INVEMAR, 2001
Coral reef	Coral reef area cove	Area	Diaz *et. al* 2000
Sea grasses	Sea grass areas cover	Area	Diaz *et. al* 2003
Coastal lagoons	Water bodies pertaining to the coast	Area	INVEMAR, 2001
Beaches	Sea-shore soft pebbles representation	Point	INVEMAR, 2001
Toponymy	Place-names of the Caribbean area	Point	INVEMAR, 2001
Rocky shores	Hard-shore punctual representation	Line	Ingeominas, 1998

2.3. Biodiversity assessment

Having collected the biogeographical and other complementary data on which conservation decisions must be made, surrogates representing the target of conservation must be selected. Although a wide variety of statistical and machine-learning methods have been proposed to support this selection [1, 4, 5, 9, 25, 48-50] within the research a heuristic approach was conducted meaning that the selected surrogate could not guarantee optimal (or even feasible) representations.

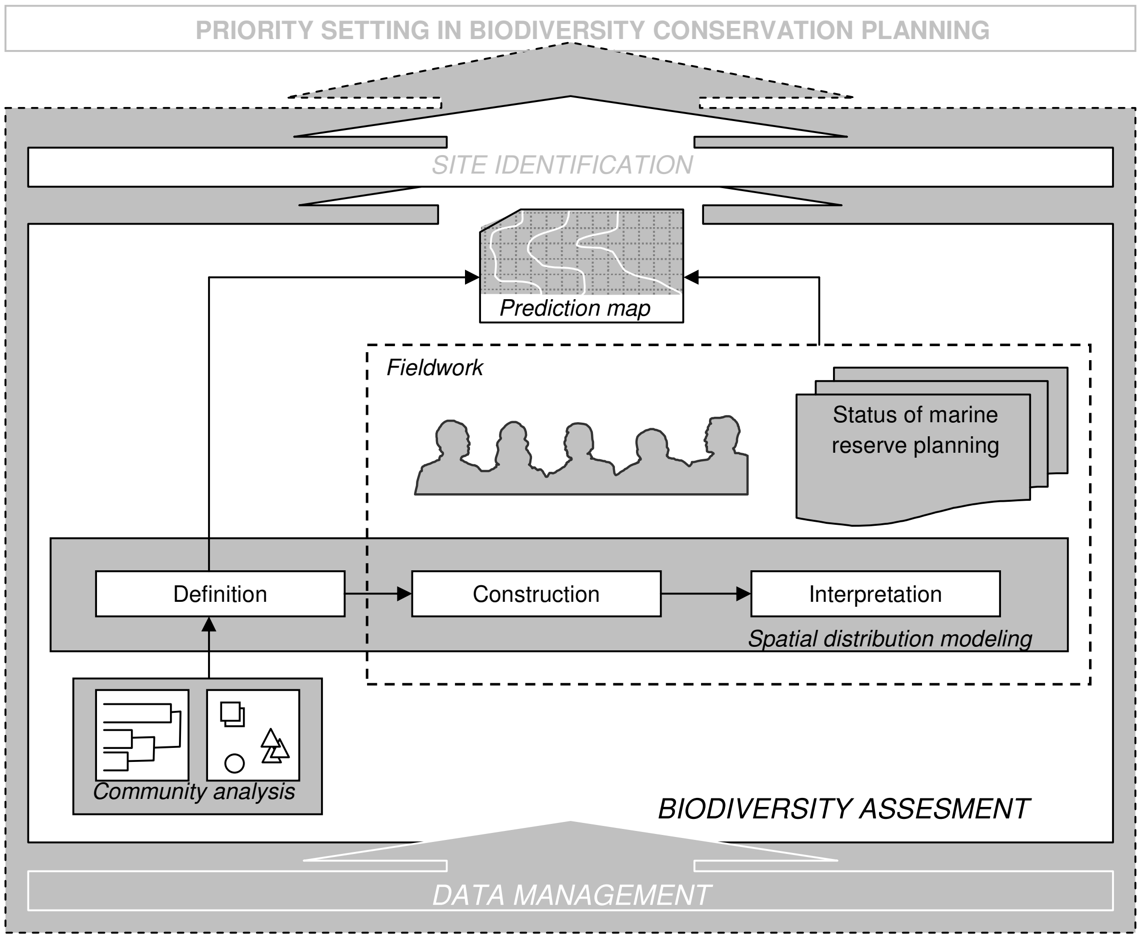


Figure 4. Research framework for the biodiversity phased

Two criteria influenced the selection of biodiversity surrogates in this study: first, the conservation target aimed by the Colombian authority responsible for managing the national protected areas, and second, the spatial distribution of *available* biotic data that allowed its representation within areas, so similarities or differences among them can be estimated.

This selection lead to the outline of conservation features used as biodiversity surrogates for the design of representative marine sites for the Colombian continental Caribbean state waters between the coastline and the bathymetric line of -600 m (). The selected grid cell size of 1 km^2 used to represent these conservation features is consider by some authors [5] as a surrogate itself because they are assumed to stand for all of biodiversity; However in this research we will not consider it as such and we will not prove its utility in that sense. Layers on national natural parks and bathymetry where used in some extent to support the conservation features in the selection site stage. All these are further described below

Ecoregions. The focus area of interest in this research cover a regional (10^4) spatial scale [48] along the Colombian Caribbean fringe. At this scale the area is divided into nine ecoregions [43] that represent unique environmental characteristics along the coast. These derived from a participative process combining expert field ecological knowledge and interpretation of existing regionalisation such as:

1) Degree of continental influence measured from fresh water, sediments and polluting agents contributions; 2). Geomorphologic characteristics and sediments types of the continental platform; 3) Coastal geomorphologic characteristics; 4) Seasonal or permanent occurrence of upwelling; 6). Presence of particular ecological units or mosaics of these; 7) Biological productivity of the water column and coastal ecosystems. This classification provides a scientific basis for reporting on the adequacy of marine environments representation in to the site selection process.

Marine benthic habitat maps. The idea of including habitat representation in the selection site is based on the concept that by conserving all habitats, the maximum number of species will be represented, including those species not used to define species assemblages [5]. From a purely ecological perspective "habitat" has been defined as the characteristic space occupied by an individual, a population or a species [18].

Habitat level surrogates have been effectively used to delineate reserves for conserving marine biodiversity [5, 24]. Two broad habitat coverage maps where used as input data in the analysis: sea grass and coral reefs coverage [38, 39]. These two unique featured classes covered a total area of 890 km^2, approximately only 2% of the total marine study area. Although available, information on the dominant species associated with the habitats was not incorporated.

National Natural Parks. This data layer provides the location for the legal boundaries of both terrestrial and marine reserves and was used to define regions within the study area that were already under protection [17]. All the represented areas are under the Colombian categorization of national parks including *Flamencos*, *Tayrona*, *Sierra Nevada de Santa Marta*, *Isla de Salamanca*, and *Corales del Rosario*. The submerged portion of these reserves is approximately 2753 km^2.

Bathymetry. Water depths can be used as a proxy for a number of physical parameters that affect macro benthos distributions across a continental slope, such as light intensity [18] and pressure [3, 24]. Bathymetry data collected in situ from original sampling points supported the macrobenthic community analysis in the definition of the species assemblages. A more general bathymetry data from the ETOPO2 Global 2-Minute Gridded Elevation Data (http://www.ngdc.noaa.gov/mgg/fliers/01mgg04.html) corresponding to the area of concern was also used.

2.3.1. Species assemblages

In the hierarchical method selected in this research, the basic unit of biodiversity, macrobenthic species, is generalized into more heterogeneous classes recognized as species assemblages (i.e. the species that occur together in a habitat at a particular place and time). Because the concept of biodiversity is broader than just the species richness, the *assemblage* of organisms in an area can be more important for its representation rather that the simple number of species present [7].

The data set used was extracted form the CCMBG corresponding to the macrobenthic inventories gather during the two surveys carried out by INVEMAR [41]. The sampling method designed in these studies aimed to represent each of the nine Ecoregions of the Caribbean platform. A total of 80 macrobenthos samples were collected using trawl survey distribution estimations in the period 1998-2001. Most sampling locations were sampled only once (Appendix 1).

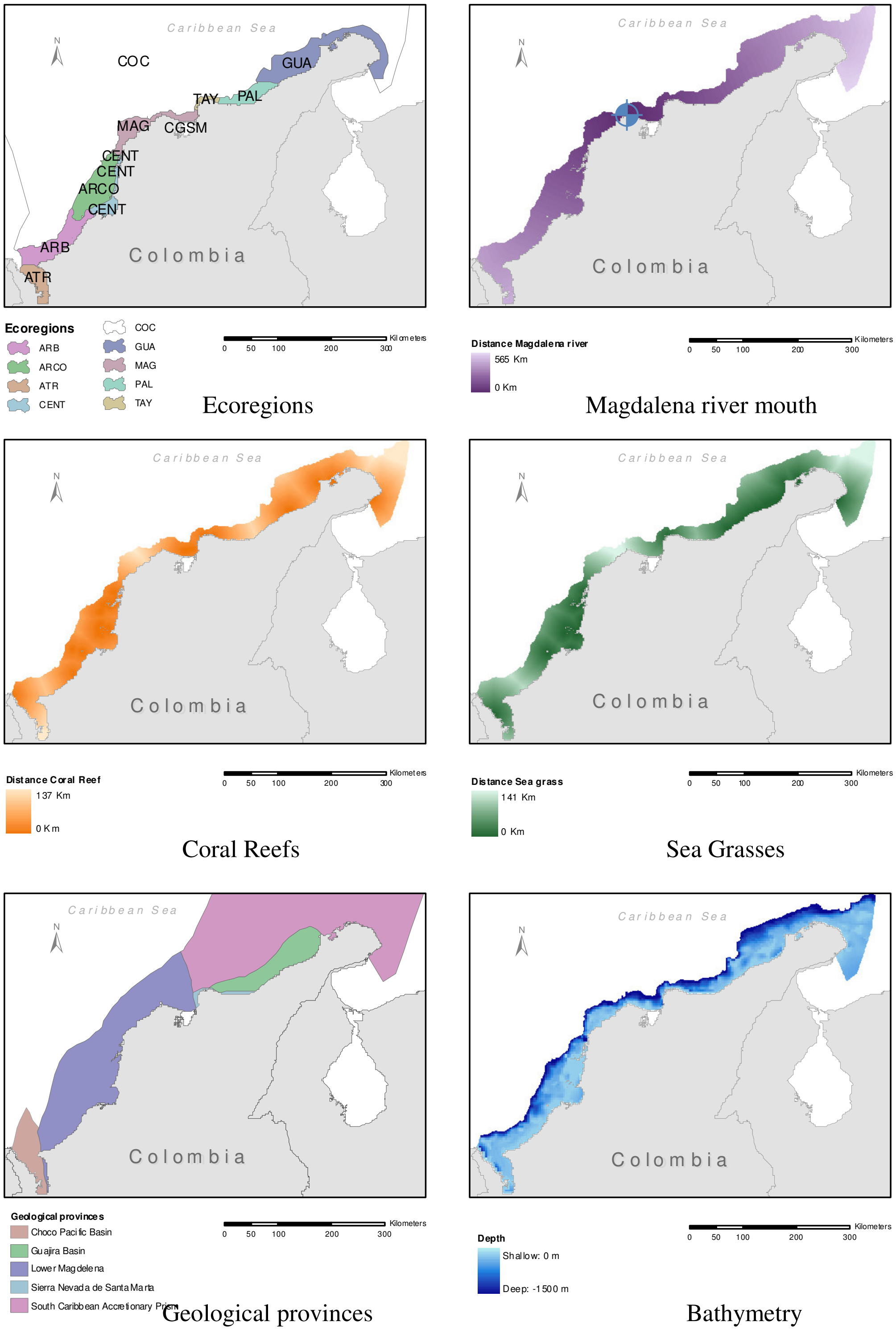


Figure 5. Spatial distribution of some environmental factors used to support the definition of the assemblage The Ecoregions and the distance maps were obtained from processing data from the CCMBG; The Geological Provinces and bathymetry from the USGS and ETOPO2 respectively.

The data set used was extracted form the CCMBG corresponding to the macrobenthic inventories gather during the two surveys carried out by INVEMAR [41]. The sampling designed of these studies aimed to represent each of the nine Ecoregions of the Caribbean platform. A total of 80 macrobenthos samples were collected using trawl survey distribution estimations in the period 1998-2001. Most sampling locations were sampled only once (Appendix 1).

The occurrence of macrobenthic species was transformed in binary (presence/absence) data. The decision of using presence/absence transformation on the data was to minimise variations on the trawl collection methods as well as in the long-term fluctuations of seasonality and extent, observed in the density data. Each of the resulting matrixes, onwards designed "Macro I" and "Macro II" were analyzed independently following the suggestions of the researchers involved in the surveys.

For diversity analysis, the © PRIMER 5 for Windows Demo of the Plymouth Marine Laboratory (PML) [49] was used . Species diversity was estimated using the Shannon-Wiener diversity index *H*' log nat base. Evenness was calculated using Pielou's *J*', and dominance was calculated with Simpson's $1\text{-}\lambda$ index. Species richness was estimated by Margalef's *D* index [50]. These indexes are described in the table below:

Table 2. Description of the univariate indexes. S *total species: the number of species in each sample.* N t*otal individuals: the number of individuals in each sample.*

Index	*Formula*	*Explanation*
Sahnnon-Weiner	$H' = \text{SUM}\ (P_i * \text{Log}(P_i))$ Log base *e*	P_i is the proportion of total number of species made up of specie *i*
Pielou's'	$J' = (H'/H'\text{max})$,	Measure of how evenly the individuals are distributed among the different species
Simpson's	$1-\lambda = 1-\text{SUM}\ (N_i*(N_i-1)/(N*N-1))$	N_i= the total number of organisms of species *i*
Margalef's	$D = (S-1)/\text{Log}(N)$	It is a measure of the number of species present, making some allowance for the number of individuals.

The community analysis was done for total macrofauna mayor taxa: Annelida, Echinodermata, Mollusca, Crustacea, Chordata and a small representative group of Cnidaria. The Bray–Curtis Cluster Analysis (single link) of the © PRIMER 5 Program was used to estimate similarities in species composition between the sampling sites.

A BIOENV (©PRIMER5) analysis to select environmental variables "best explaining" the community pattern, by maximizing a rank correlation between their respective similarity matrices was also made. Because only depth was taken at the time of trawling (initial and final) some other environmental variables were extracted from the CCMBG to improve the assessment. Distance to the Magdalena River [51] and the distance to coral reefs and sea grasses cover, were considered factors that could influence the distribution of the macrobenthic community. The X and Y values of the collecting site were also considered as factors [52]. The qualitative representation of geological provinces and ecoregions division were as well included in the analysis.

An ANOSIM (©PRIMER5 - analysis of similarities) was also performed to determine differences between the macrobenthic assemblages. This analysis summarises the composition between pairs of assemblages into a single measure of similarity; a 100% similarity means that they are identical [53]. It provides a measure of difference called *R*. When *R* is near to 0, differences between assemblages are no larger than one another in any place. When R is near to 1, then it is reasonable to be confident that the assemblages do contain different species to be considered a group [54].

Characteristic and discriminating species of each assemblage were determined using Similarity Percentage (SIMPER) analysis in the same © PRIMER 5 program. To identify characteristic features, SIMPER calculates the average Bray-Curtis similarity between all pairs of assemblages. Because the Bray-Curtis similarity is the algebraic sum of contributions from each species, the average similarity between sites of the groups can be expressed in terms of the average contribution from each species. The standard deviation provides a measure of how consistently a given species contributes to the similarity between sites [10].

Despite the large data set, there is no general knowledge on possible occurrence changes of the macrobenthos appeared in the study area. Neither there is enough evidence that suggest that the species being present in a certain environment are not accidental observations. This situation will inevitably introduce error into the resulting data but within the interpretation and not the generation of the predictions itself relays the biggest uncertainty. As a way of overcoming the neglect of ecological knowledge as a limiting factor in the statistical modelling of the data, a group discussion with some experts in Colombia was carried out during fieldwork period.

Thus far, the results of community analysis and definition of assemblages give as a result a punctual localization. In order to predict their potential distribution along the study area, the GARP modelling system was used.

2.3.2. Assemblages potential distribution

The ©DesktopGarp Program is a desktop version of the GARP algorithm (Genetic Algorithm for Rule-set Production) [55]. GARP searches iteratively for non-random correlations between species presence and absence and environmental parameter values using several different types of rules: atomic, logistic regression, bioclimatic envelope, and negated bioclimatic envelope. Among these the logistic regression rules [8] has previously proven successful in predicting macrobenthic species response along estuarine gradients [56].

To model the assemblages' patterns several steps within the program have to be followed; the input of data points, the selection of environmental layers, the setting of the optimization parameters, and the setting of the output parameters. Once all these are set, the execution of the model begins.

Data preparation. Each of the resulting assemblages was expressed as point coverage is an ASCII files (latitude and longitude) for geographic location. Six abiotic environmental parameters were used to predict the probability of occurrence of the assemblages: bathymetry, marine geological provinces, ecoregions, distance to the Magdalena river mouth, and the distance to the coral reefs and sea grasses areas. The use of distance to the Magdalena river mouth intended to represent the influence that this Turbidite System [51, 57] has on these ecological communities as suggested by personal communications from ecological experts studying the area. The distance to the benthic habitats were included to represent the vast area encompassing the life history assemblages seasonal distribution [20, 58].

All the environmental layers had to be produced in a compiled *DG dataset* to be used in GARP. They were exported from the CCMBG to ASCII Raster Grid format, placed on the same directory as GARP, and adjusted to the same geographical boundaries and the same cell size (1 km^2).

Optimization parameters. Each of the assemblages was treated independently to generate a single prediction map. At least 30 % of the samples were used for training of the model. A standard convergence limit of 0.01 and a value of 1000 maximum iterations were set were set for all the executions. Because all the type of rules where selected, for any particular portion of the search space (all possible combinations of variables) the best describing the relationship among the variables was used [59]. The number of runs varied from 200 and 350 until an acceptable BestSubset selection was gained. A 10% of extrinsic omission measure was used for this selection.

All the selected environmental layers were used in each execution. The resulting objects of all the models and the resulting tables were saved for criteria for the selection of the optimal model calculating the intrinsic and extrinsic measures of omission and commission error [60]. The output prediction map for each assemblage was produced in ESRI Arc/Info grids and incorporated into the CCMBG for its use in the site identification phase described below.

2.4. Site identification

In this stage, the spatial representation of biodiversity surrogates were used as conservation features for the selection of sites. Nevertheless, whether the selected surrogates empirically represent the total species diversity is a question that remains and should be explored in later studies.

The selected sites should collectively represent as much of the available biodiversity of the study area as possible [5]. By this criterion (representativeness principle), the selected sites should contain at least one example of every conservation feature present in the area of interest [61]. However because there are constrains for amount of area that could be potentially set aside for a later prioritization process, it is prudent to set sites that achieve a comprehensive representation on a minimum extent. This is identified as the minimum representation problem [62] and is traduce into a linear function of the number of sites in the system.

Several software packages have been developed to assist this selection procedure: (ResNet [26], COST [63], OPL Studio and CPLEX [64], BioSelect [7], CPLEX, GAMS [65], GRASP (spatial prediction) [66], C-Plan [67] among many others. Being aware that evaluating the utility of each of these packages was far beyond the objectives of the present research, the selection of the MARXAN software was made.

The MARXAN (Marine Spatially Explicit Annealing) software was developed for the specific use as a decision support tool for marine reserve design [24, 68]. It has proven its utility in a case study in South Australia to design a systematic marine reserve [62] and thus this experience was reproduced and analyzed in this study. The outcomes will serve as a basis for the exploration of how this approach could complement or support Colombian marine biodiversity conservation planning process.

2.4.1. Tessellation and pre-processing

Three classified data layers indicating the marine biodiversity of the Colombian Caribbean region became the proxy data for the site selection: benthic habitats (coral reefs and sea grasses), ecoregions and macrobenthic species assemblages. These layers resumed 20 *conservation features*, the term used in here to refer to biodiversity entities included in the analysis.

A sampling grid with hexagonal cells of 9 km^2 approximately was created as a basis for reserve selection over the study area. The resultant 4,860 grid cells are referred as *planning units* –PU in the optimisation model. The percentage of cover area of each of 20 conservation features was quantified for each planning unit using ESRI ©Arc Map™ 9.0. The area of each site was also calculated and used as a cost in the optimisation model. The National Natural Park data layer was used to define regions within the study area that were already reserved. All cells and cell segments that overlapped with these protected areas were classified as existing reserves.

2.4.2. Integer programming

MARXAN uses a mathematical reserve selection algorithm that falls somewhere in between a heuristic and an optimisation tool as it uses simulated annealing to find local minima to the reserve selection problem, but cannot guarantee the global optimum [24, 69, 70]. The mathematical minimum representation problem implemented for systematic site selection in this study is described below (adapted from McDonnell *et al.*, 2000).

To describe the problem for the given data set, let

m = total number of PU (4,895 cells);

n= total number of conservation features (20) present in the PU;

d_i = total area percentage of PU i (in %), $\forall i = 1, 2, \ldots, m$ ($d_i > 0$);

a_{ik} = area percentage (9 km^2 =100%= 100) of conservation value k on PU i, $\forall i = 1, 2, \ldots, m$, $\forall k = 1, 2, \ldots, n$ ($a_{ik} \geq 0$);

b_{ij} = length of shared boundary (in m) between PU i and j , $\forall i = 1, 2, \ldots, m$, $\forall j = 1, 2, \ldots, m$ ($b_{ij} \geq 0$ and $i \neq j$);

β_i = total boundary length (in m) of PU i, $\forall i = 1, 2, \ldots, m$ ($\beta i > 0$).

Also, let

c_k = required area percentage (9 km^2 =100%=100) of conservation value k, $\forall k = 1, 2, \ldots, n$ ($c_k \geq 0$);

BLM= Boundary Length Modifier (c*k* and BLM are adjustable parameters specified prior to running the algorithms).

A state vector **x** of control variables indicates whether PU are included in the reserve:

$\mathbf{x} = (x_1, x_2, \ldots, x_m)$, where

x_i =1, if PU i is included in the reserve,

x_i =0, otherwise.

So if **x** is the set of all possible state vectors **x**, then mathematically we wish to find the vector ^x $\in$ X which minimises the "cost" of the reserve, while meeting representation constraints. Our objective or cost function here is the sum of area and weighted boundary length:

$$C(x) = \text{BLM} \times B(x) + \Sigma\, d_i x_i \,, \qquad (1)$$

where the total boundary length of the selected sites $B(x)$ is given by

$$B(x) = \Sigma\ \beta_i x_i - 2\ \Sigma\Sigma b_{ij}\ x_i x_j \qquad (2)$$

Thus, the problem of minimising the cost, $C(x)$, subject to the representation constraints can be written as a mathematical programming problem:

Minimize the objective function

$$C(x) = \text{BLM} \ \times B(\mathbf{x})\ \Sigma\ d_i x_i$$

subject to the constrains

$$\Sigma\ a_{ik}\ x_i \geq c_k,\ \forall k = 1, 2, \ldots, n,$$
$$x_i \in \{0, 1\},\ \forall i = 1, 2, \ldots, m$$

where x_i is the control variable such that if x_i =1 then PU is selected and if x_i = 0 then PU i is not selected.

2.4.3. MARXAN selection

The two main steps in using the program are setting up the data and then running different options on the data to achieve the desired comprehensive representation. Feedback elements in the process were necessary to accomplish the selection.

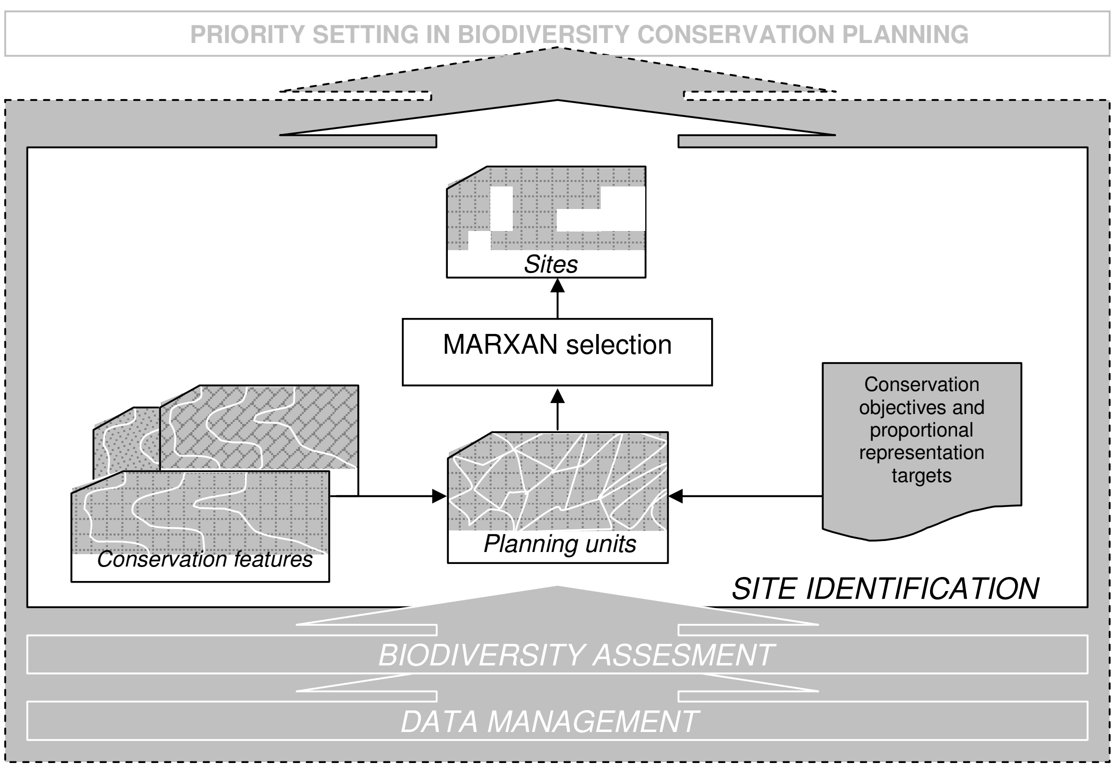


Figure 6. Research framework for the site identification phase.

Scenario setting. The site selection problem was set for two consecutive scenarios: the "*No reserve*" and the "*Seed PU*". An initial scenario (*No reserve*) without the inclusion of the Natural Park areas was made and thus ignoring the status of the Colombian Caribbean existing marine reserves. The control variable x_i assumed a value of either 0 or 1 for all 4,895 PU. If $x_i = 1$, then that planning unit was selected, and if $x_i = 0$, then PU i is excluded from the selection. The cost variable $C(x)$ was set to 1, which means that every PU has equal cost. The boundary length modifier (BLM) was fixed at 0.5 to minimise fragmentation and to produce both reasonably compact and an efficient site selection. The target setting of for representation for each conservation feature was set as 30% for the habitats and the assemblages and 10% representation for the ecoregions.

For the *No reserve* scenario, we used the Pure Greedy Heuristic optimisation methods for the objective function [71]. This algorithm values PU according to the change, which they give to the objective function and might not continue until every conservation feature is represented. This method allowed to contain all the complexity added to the objective function, notably with regard to a conservation feature aggregation and segregation rule, and the boundary length of the reserve system. An iterative improvement optimization method under the same scenario settings was then applied to ensure that no improvement was possible using the selected sites as seeds.

In the *Seed PU* scenario, the control variable x_i now assumes a value of either 0 or 1 for only 4283 planning units. The site selection design problem is to make additions to the 306 sites that contain Colombian Caribbean existing marine reserves until conservation targets are met. The two scenarios presented two different site selection problems (with out counting the seven trial feedback experiments), with 1000 independent runs of the algorithm performed for each.

The *best solution* for all the runs in each scenario was selected; this solution file is given by MARXAN and consists of a list of planning unit IDs that constitute the selection. The *summed solution file* also produced by MARXAN, keeps track of how often each planning unit was involved in any solution. This value serves as an indicative of the irreplaceability principle. An irreplaceable PU would be defined (based on the selection frequency), as those selected more times that could be expected from chance alone. If a planning unit is selected in all runs (1000) it is defined as *100% irreplaceable;* Between 999 and the highest bin of the distribution the PU is defined as *irreplaceable*. The best solution and some examples of the frequency selection of sites solutions were exported to ESRI ©Arc Map™ 9.0 for representation and analysis.

A summary of the proportion of planning units identifying conservation features within each scenario is also given. The performance of the solutions to identify key components and existent marine reserve sites (NNPS areas) served as a basis for assessing the effectiveness and convenience of its use as a complementary tool in the procedures to prioritise biodiversity conservation sites

3. Results

3.1. Spatial dimension of macrobenthic species

The total catch of macrobenthic species on 80 benthic trawl stations (MacroI and MacroII surveys) included 1209 species belonging to 7 phylum's Annelida, Arthropoda, Chordata, Cnidaria, Echinodermata, Mollusca and Porifera (Appendix 1). Mean total abundance per station varied between 50 and 7419 with an average of 921. Two mollusc species were by far the most abundant, *Limopsis sulcata* and *Entalinopsis callithrix* (with 8946 and 2692 individuals respectively). From the total, 345 species were represented just by one individual.

3.1.1. Community analysis

Cluster analysis based on presence/absence macrobenthic species showed a clear separation of stations at an arbitrary level of 40% and 20 % Bray-Curtis similarity (Figure 7). The first dendrogram comprises stations sampled between 300 and 500 m depth with the exception of stations INV 019 and INV 023, where sampling depth was 200 m. The second dendrogram is composed of stations taken between 20 and 500 m. Station INV 043 (*) was included into assemblage 6 based on further similarity analysis (SIMPER).

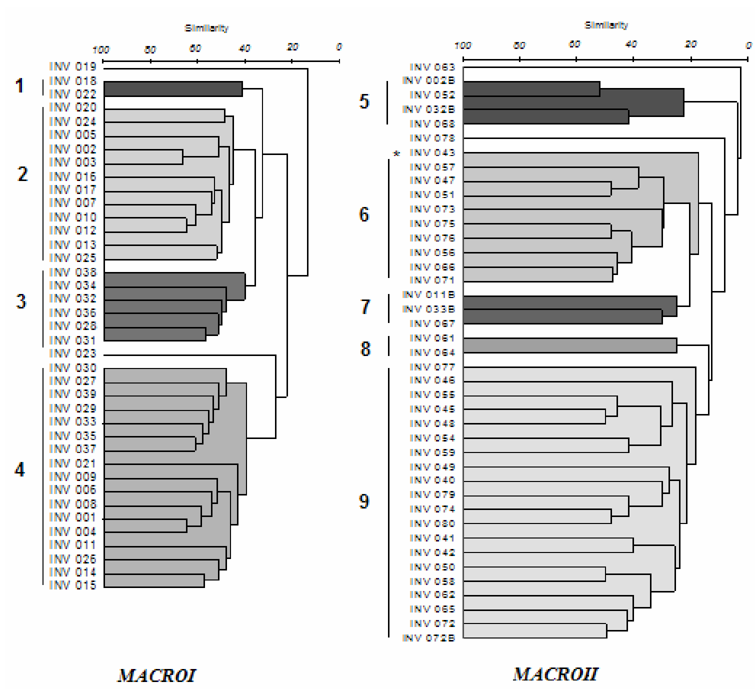


Figure 7. Dendrograms for hierarchical clustering of the 39 (MacroI) and 41 (MacroII) sites using group-average linking of Bray-Curtis similarities calculated on presence-absence abundance data. The assemblages described in Table 3 match the numbers beside the stations.

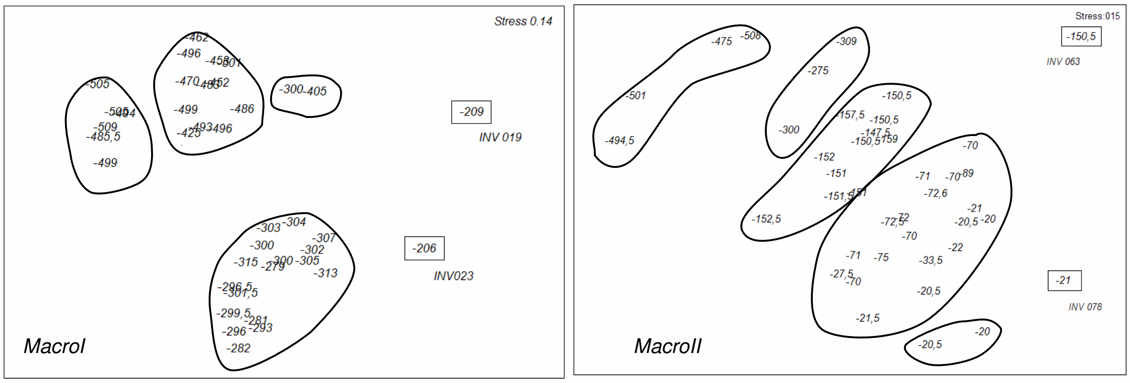


Figure 8. MDS plots for the 80 stations according to the macrobenthic assemblage; the numbers refer to the sampled depth

The separation of stations by depth is confirmed by the ordination with MDS of the same assemblage data (Figure 8). The stations collected closed to 300 m separate from those at 500 m depth; observe that the two stations that separate from the main groups were collected at 200 m depth. This same pattern was consistent in the second survey data. The samples from shallower waters (between 20 and 150 m depth) tend to separate themselves from the deep waters (300 and 500 m).

The importance of depth also could be depicted from the BIOENV analysis. The maximum matching coefficient was achieved by the abiotic variable depth in both data sets (74.7% MacroI and 72.4% MacroII) and supported therefore the result from the MDS and cluster analyses. Ecoregion (73% and 72%, respectively) and geological provinces (71.2% and 67%, respectively) were further useful environmental parameters to explain the observed pattern in the macrobenthic community. Other abiotic variables showed also good correlation with the biotic similarity matrix and yielded matching coefficients above 55%.

Table 3. SIMPER analysis of similarity between macrobenthic assemblages of Figs. 6 and 7. The term AVG Similarity represents the overall average similarity of each assemblage. Av.Abund represents the average abundance of each species. AV.Sim represents the average similarity of each species contributing to the similarity between assemblages. Sim/SD is the ratio of contribution average/standard deviation. Contrib% is the average contribution/average dissimilarity between assemblages. nc=no calculated

Assemblage	AVG Similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%
1	41,03	*Penaeopsis serrata*	20,50	1,71	nc	4,17
		Gaza olivacea	12,50	1,71	nc	4,17
2	48,55	*Glyphocrangon neglecta*	79,92	1,20	8,85	2,47
		Hyalinoecia artifex	26,42	1,20	8,85	2,47
3	46,76	*Hyalinoecia artifex*	25,67	1,53	6,26	3,28
		Glyphocrangon neglecta	20,17	1,53	6,26	3,28
4	44,29	*Munida longipes*	55,35	1,15	10,25	2,59
		Neobythites gilli	48,12	1,15	10,25	2,59
5	30,47	*Glyphocrangon neglecta*	40,00	1,58	9,76	5,17
		Prionocrangon pectinata	38,25	0,82	0,91	2,70
6	31,34	*Portunus spinicarpus*	54,00	1,57	5,20	5,01
		Citharichthys cornutus	13,20	1,20	1,85	3,84
7	26,59	*Penaeopsis serrata*	123,00	1,32	16,96	4,98
		Parapeneus politus	24,33	1,32	16,96	4,98
8	24,81	*Mulinia cleryana*	32,00	1,55	nc	6,25
		Trachycardium muricatum	12,50	1,55	nc	6,25
9	24,73	*Portunus spinicarpus*	38,45	1,04	1,34	4,21
		Macoma tenta	17,65	0,92	1,18	3,71

An analysis of similarity (ANOSIM) was performed to test for statistical differences in species composition between the different assemblages. A value of *R= 0,947* and *R=0,804* (MacroI and MacroII respectively; *P=0.01*) supported the results of the classification and ordination of the data and indicated significant differences in species composition between the assemblages.

The similarity percentage procedure (SIMPER) was applied to identify those species that contribute most to the observed differences between macrobenthic assemblages. Table 3 summarises this result and defines the two mayor contributing species; their names were given to them.

The calculation of several univariate indices for the species abundance reflected differences between the macrobenthic assemblages (Table 4). The average number of species did not vary greatly among the assemblages although the differences on the number of sampling sites composing each of them are notorious. On the other hand, the average number of individuals does tend to reflect this fact. The observed differences in the Margalef's diversity, Pielou's evenness, Shannon's diversity and Simpson's diversity indexes average values were quite similar among the assemblages and were not statistically significant.

Table 4. Univariate indexes of the macrobenthic assemblages; n. ind.= number of individuals per station, n.spp= number of species per assemblage, d=Margalef's diversity, J'= Pielou's evenness, H'(loge) =Shannon's diversity, 1-Lambda'= Simpson's diversity. All the indexes are expressed in average values.

Assemblage	*n._ind*	*n_spp*	*d*	*J'*	*H'*	*1-'λ*
Penaeopsis serrata-Gaza olivacea	289	59	9.985	0.720	3.051	0.918
Glyphocrangon neglecta-Hyalinoecia artifex	1500	85	13.136	0.701	3.133	0.883
Hyalinoecia artifex-Glyphocrangon neglecta	384	67	12.493	0.735	3.206	0.904
Munida longipes-Neobythites gilli	861	88	12.084	0.685	2.989	0.862
Glyphocrangon neglecta-Prionocrangon pectinata	1559	64	10.888	0.720	3.042	0.861
Portunus spinicarpus-Citharichthys cornutus	507	66	11.222	0.730	3.103	0.896
Penaeopsis serrata-Parapeneus politus	954	76	9.623	0.696	2.855	0.868
Mulinia cleryana-Trachycardium muricatum	313	65	8.120	0.809	3.124	0.937
Portunus spinicarpus-Macoma tenta	1090	78	10.917	0.740	3.042	0.907

3.1.2. Spatial assemblages prediction

At the scale of the whole study area, the spatial distribution of some of the univariate indexes described before, show a similar patterns when mapped: Species richness (Appendix 4) shows greater values along the central region (Bahía de Santa Marta, Figure 2) as well as in deep waters from this area south. This same pattern is consistent with the diversity and evenness indexes. However, the mapping of these simple surrogates is not enough for the site selection process intended in the research.

Further more, the community analysis defining the macrobenthic assemblages just gave as a result the punctual localization shown in Figure 9. Because of the lack of an a priori known relationship between these assemblages and the environment, an inductive- descriptive approach was used to derive their ecological requirements from the location they occur [48].

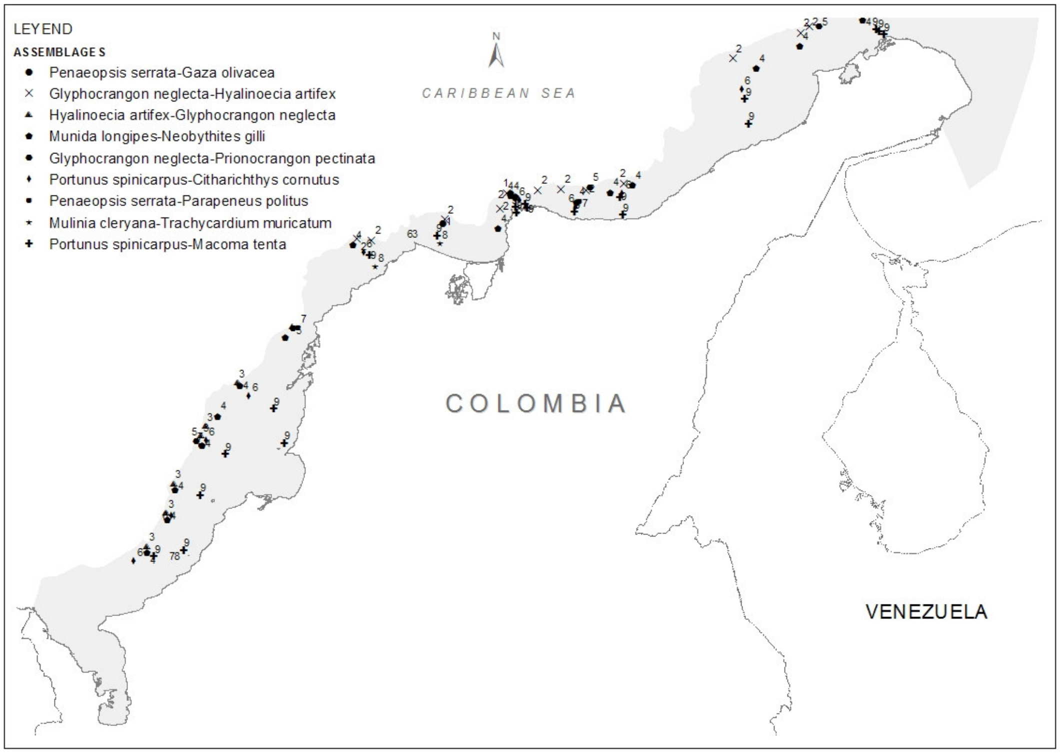


Figure 9. Map of the observed distribution of the nine assemblages defined by the community analysis.

In order to model the potential distribution of these assemblages, the Genetic Algorithm for Rule-Set Prediction GARP was used. Seven environmental variables for each model were incorporated besides the depth: distance to the Magdalena River, distance to the coral reef and sea grasses areas, sediment types, ecoregions and marine geological provinces. This selection was supported by the results of the environmental explanatory analysis (BIOENV) made earlier.

Within each assemblage, the confusion matrix as well as a visual recognition of the distribution maps aided to make the final selection (Table 5). The best distribution models were found compensating a low commission and relatively low omission values. These can be seen in Figure 10a and 10b.

Table 5. Measures for the overall performance of the models representing the macrobenthic assemblages distribution.

Assemblage	*Commission*	*Omission (ext)*
Glyphocrangon neglecta-Hyalinoecia artifex	5.9	37.5
Glyphocrangon neglecta-Prionocrangon pectinata	10.4	33.3
Hyalinoecia artifex-Glyphocrangon neglecta	4.8	0.0
Mulinia cleryana-Trachycardium muricatum	4.3	0.0
Munida longipes-Neobythites gilli	9.3	25.0
Penaeopsis serrata-Gaza olivacea	4.6	0.0
Penaeopsis serrata-Parapeneus politus	2.0	0.0
Portunus spinicarpus-Citharichthys cornutus	7.1	20.0
Portunus spinicarpus-Macoma tenta	23.3	40.0

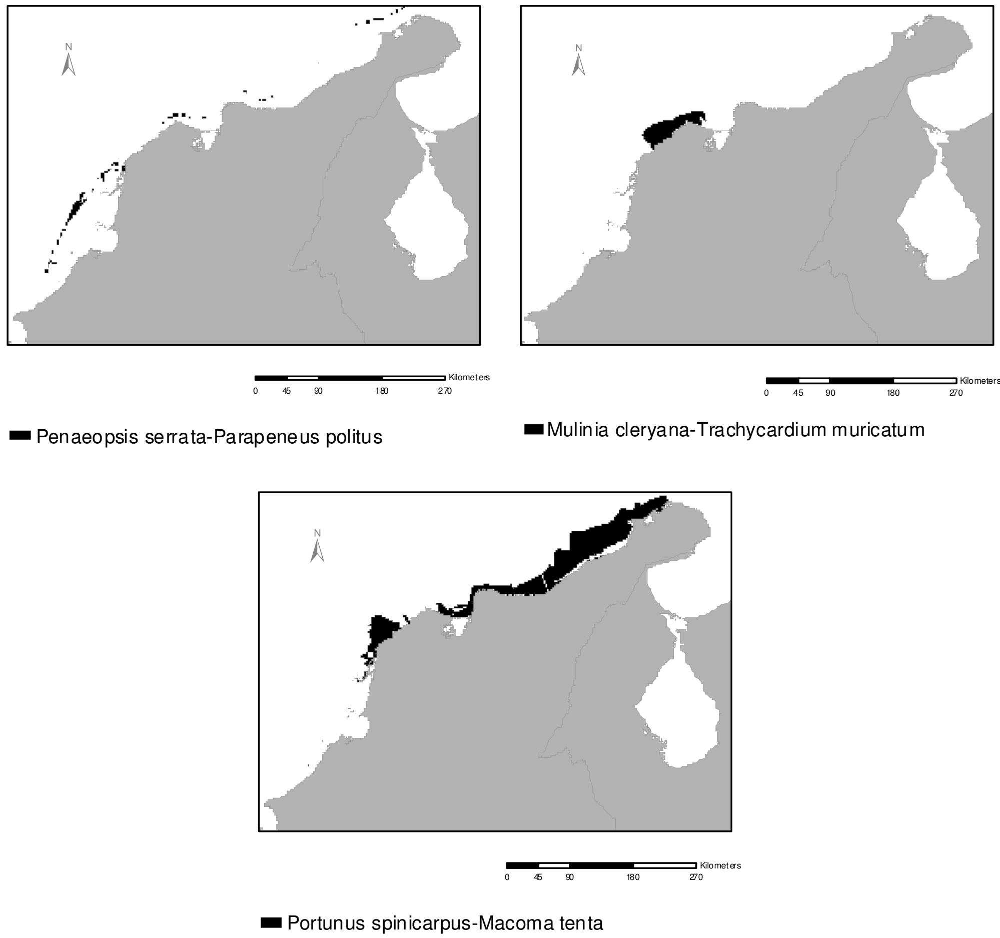


Figure 10a. Maps of the modelled potential distribution of the macrobenthic assemblages in the study area.

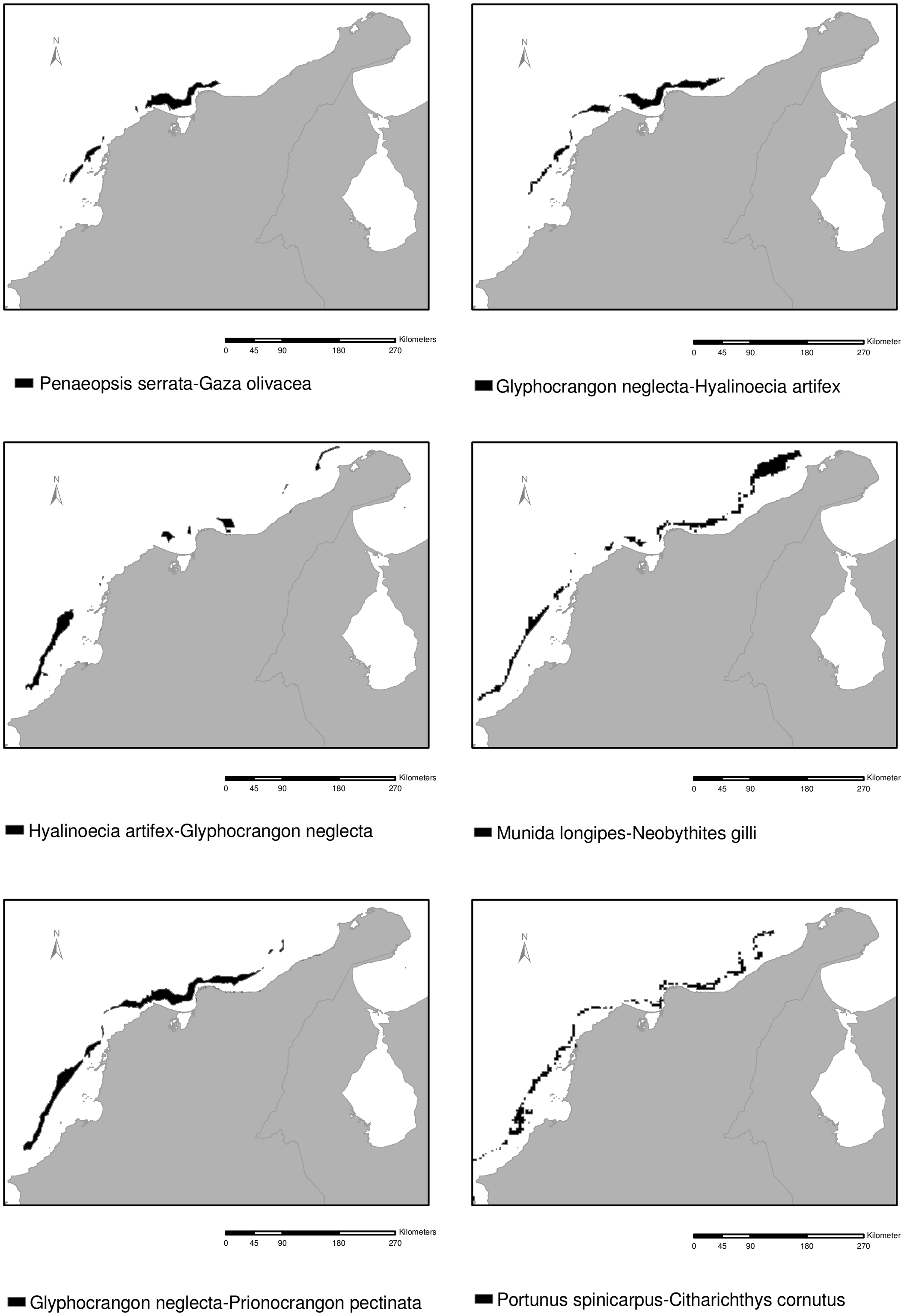


Figure 10b. Maps of the modelled potential distribution of the macrobenthic assemblages in the study area.

3.2. Biodiversity surrogates acounted for site identification

Eleven experiments were produced in the MARXAN software searching for the two best comprehensive representations of the conservation features (Appendix 7) within the available planning units-PU. The best solution from each run of the progressively improving experiments was selected to stand for the two scenarios: the "*No reserve*" and the "*Seed PU*". For both scenarios, 4895 PU and 20 conservation features were used. The conservation values and the target selected for each conservation feature are resumed in Table 6.

Table 6.Conservation features used in MARXAN. k = *conservation value;* c_k = *percentage of required* k.

Conservation feature	*k*	c_k	*target*
Benthic habitats			
Coral reef	6863	30%	2059
Sea grass	5378	30%	1613
Macrobenthic assemblages			
Penaeopsis serrata Parapeneus politus	9239	30%	2772
Glyphocrangon neglecta Hyalinoecia artifex	26849	30%	8055
Glyphocrangon neglecta Prionocrangon pectinata	47996	30%	14399
Hyalinoecia artifex Glyphocrangon neglecta	22421	30%	6726
Mulinia cleryana Trachycardium muricatum	19956	30%	5987
Munida longipes Neobythites gilli	42910	30%	12873
Penaeopsis serrata Gaza olivacea	20954	30%	6286
Portunus spinicarpus Macoma tenta	107970	30%	32391
Portunus spinicarpus Citharichthys cornutus	32778	30%	9833
Ecoregions			
Guajira- - GUA	91599	10%	9160
Tayrona - TAY	4415	10%	441
Palomino - PAL	24327	10%	2433
Magdalena - MAG	36269	10%	3627
Centro - CENT	4973	10%	497
Caribe Oceanico Continental - COO	16240	10%	1624
Atrato -ATR	22609	10%	2261
Archipiélagos Coralinos - ARCO	55018	10%	5502
Arboletes - ARB	22609	10%	2261

Figure 11 shows the selected sites for each of the scenario after setting the conservation targets mentioned in Table 6. Both scenarios were successful in achieving their goals (representativness of the planned conservation targets). The *No reserve* scenario selected 691 PU covering an approximated area of 6200 Km^2. The *Seed PU* scenario selected 904 PU covering an area of 8135 Km^2.

The PU proportion identifying *benthic habitas* as well as areas under actual protection by the NNPS, are expressed in Table 7. The total cover area of each conservation feature represents the actual estimation obtained by the GIS; The cover area of the PU estimated for each scenario sum the area of one PU (9 Km^2) times the number containing each the conservation feature. Thus, this area does not reflect the actual cover estimation selected by the solution, but the percentage of planning units that contains the conservation feature.

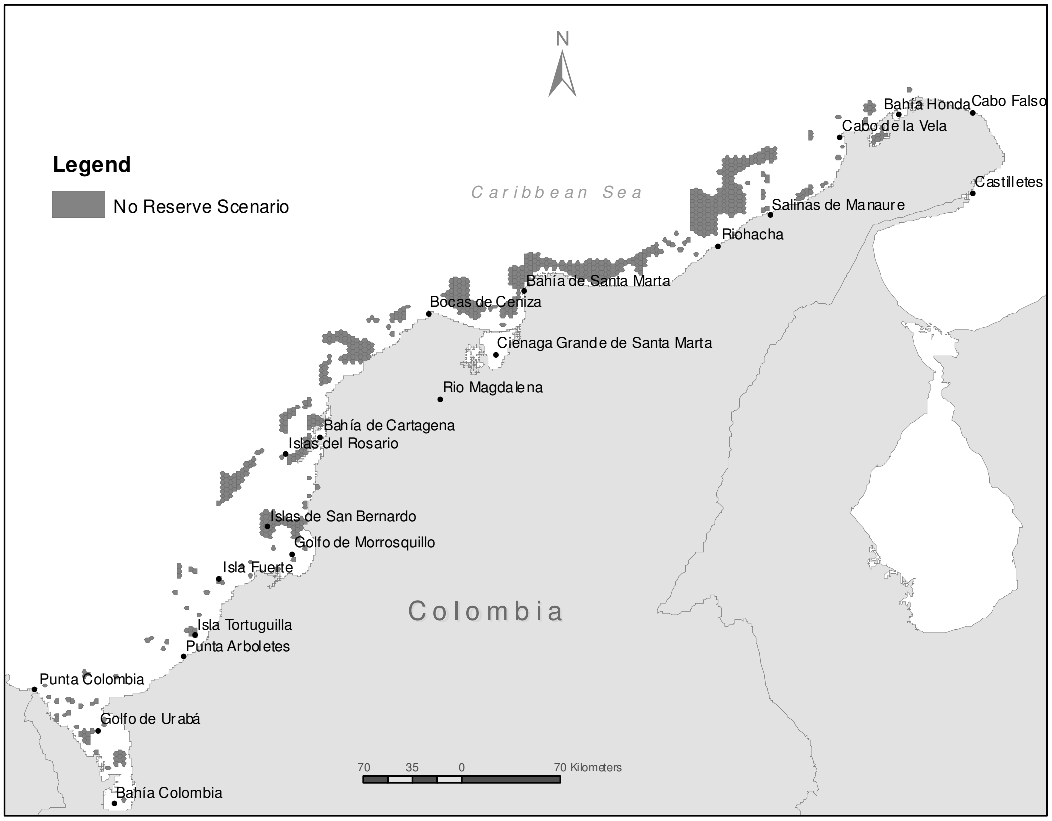


Figure 11. Selected PU by MARXAN for the "No reserve" and "Seed PU" scenarios.

Table 7. Summary data for the best site selection problems generated for the two scenarios. PU=Planning units, %PU=Percentage of the total number of PU within each conservation feature; Cover area expressed in Km^2.

Conservation features	Total		Scenario					
			No Reserve			Seed PU		
	PU	Cover area	PU	% PU	Cover area	PU	% PU	Cover area
Coral Reefs	215	617	65	30,2	585	116	54,0	1044
Sea Grasses	262	484	78	29,8	702	73	27,9	656
NNPS areas	306	1984	61	19,9	549	306	100	2753

Figure 12 thru Figure 15 illustrate some examples of the selection frequency of each PU involved in the solutions. Included also are the actual marine areas under the protection of the National Natural Park System (NNPS). Only those areas pertinent for the marine territory are shown. The irreplaceable PU from each scenario are identified in the figures by a red colour corresponding to the highest values of the distribution. The blue colour, corresponding to the lowest values of the distribution suggests a random detection.

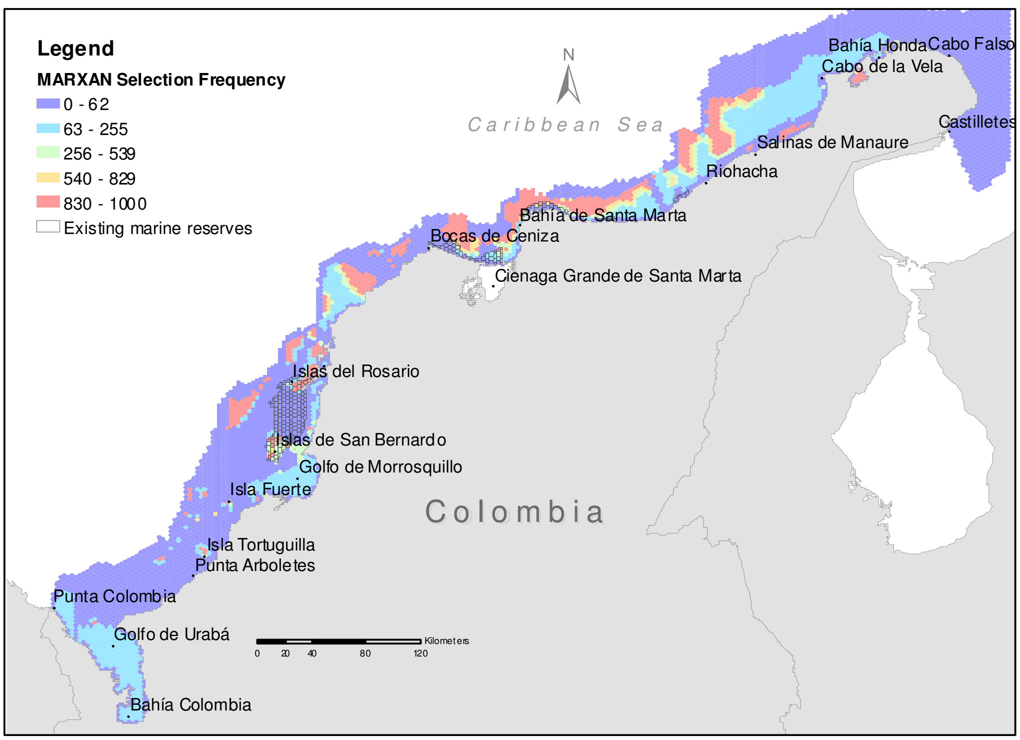


Figure 12. Map showing the MARXAN selected sites for the No reserve scenario, using the heuristic greedy algorithm with BLMs of 0.5. The existing reserves are not guaranteed to be included in the initial seed planning units.

The example in Figure 10 illustrates the distribution of and for the *No reserve* problem using the heuristic greedy algorithm and a BLM of 0.5. From the total number of PU (4895), 387 were identified as 100% irreplaceable and 60 PU as irreplaceable. These are mainly located north of the

Bocas de Ceniza (Magdalena river mouth) and clumped around the Santa Marta sector. Two mayor key areas can also be recognized along the deep platform in front of Riohacha. This cluster distribution is consistent with the solution represented in Figure 9.

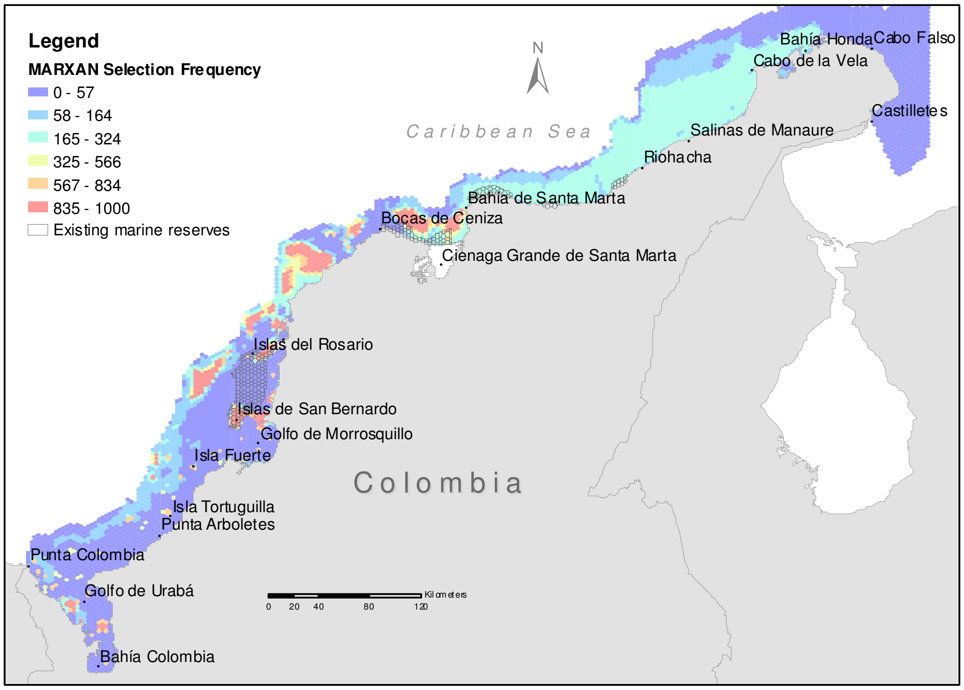


Figure 13. Map showing the MARXAN selected sites for the No reserve scenario, using the Iterative Improvement algorithm and the PU selected in Fig 10 as the initial seed; these may or may not be included in the final selection. BLMs of 0.5

To try to improve the solution obtained from the *No reserve* problem the iterative improvement algorithm in MARXAN was used using the obtained PU as initial seed. The resulting map is show in Figure 11. This problem reduced the irreplaceable sites around the Santa Marta region but keeping the representation between Bocas de Ceniza and north of Islas del Rosario. This algorithm allowed to highlight, although in smaller patches, the representation of conservation features in the Golfo de Uraba south of the study area.

Two solutions for the *Seed PU* scenario demonstrating the site selection frequency can be seen in Figures 12 and 13. Using the current NNPS areas as PU seed for the problem, 656 PU were identified as 100% irreplaceable and 64 as irreplaceable. These key areas are again clumped closed to the Santa Marta region.

By keeping fixed the NNPS areas in the same *Seed PU* scenario problem (Figure 13), a similar representation is obtained. Highlighted in this solution are key representative areas in the Golfo de Uraba absent in the previous one (Figure 12).

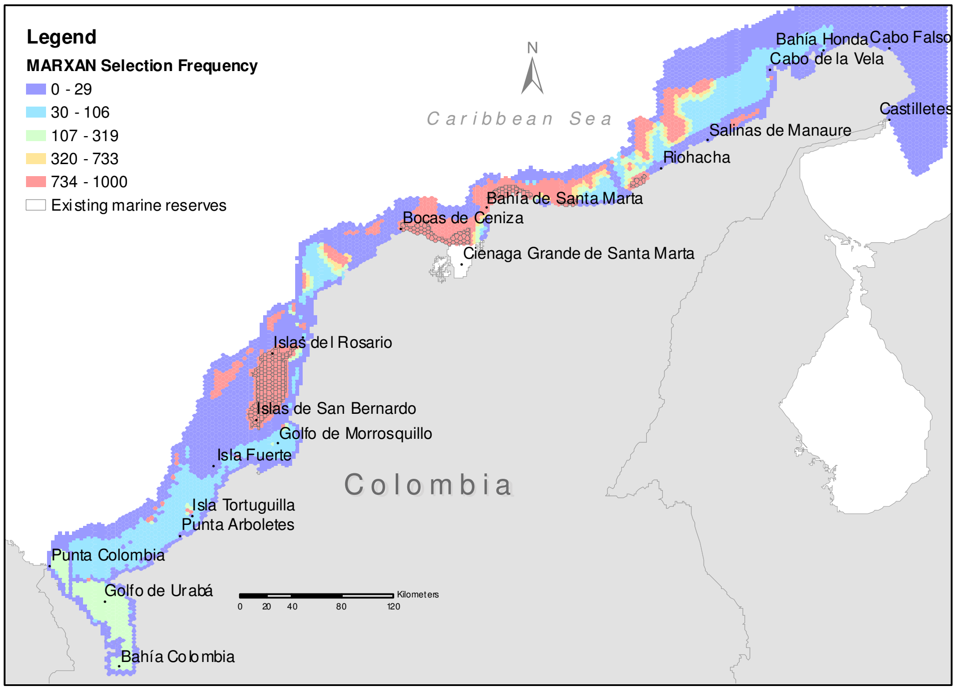


Figure 14. Map showing the MARXAN selected sites for the Seed PU scenario, using the heuristic greedy algorithm with BLMs of 0.5. The existing reserves were included as initial seeds they may be or not included in the final selection.

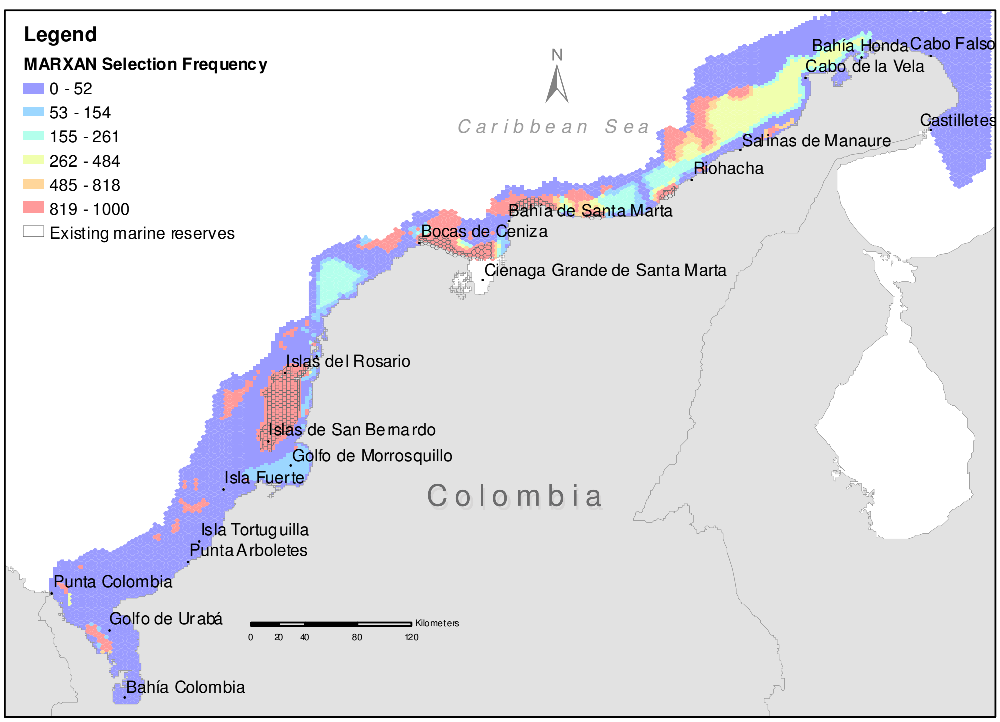


Figure 15. Map showing the MARXAN selected sites for the Seed PU scenario, using the heuristic greedy algorithm with BLMs of 0.5. The existing reserves were included as initial seeds and could not be removed from the final selected

4. Discussion and conclusions

Systematic conservation planning is a very dynamic process. The basic ecological, economical and human communities' information need to be properly referred to the scale and the time frame of the problem of concern. In this research, we have focused our attention to the regional representation of macrobenthic biodiversity to asses its potentiality as a tool supporting conservation site prioritization. This regional approach although could be criticised for being too broad and general, allowed to set general patterns as well as information needs for related present and future initiatives. It is the general research methodological framework and not the outcomes as such which sets the basis for a motivating analysis.

Starting with the supporting primary data several considerations could be made. Although storage data managers in Colombia are investing huge efforts in keeping spatially primary data integrity, it was very difficult to keep track of its basic metadata. The quality of the data for the purposes of this research was very important and unfortunately, it was quite variable. In some cases, highly skilled professionals such as the ones involved in the macrobenthic inventories had done the original data compilation. In some others, geographically reference records compiled in the SIBM were of doubtful quality. Much of the data provided was of variable scales, resolution and geographical extent.

Two big sets of digital data were used containing spatial features representations and geographical records from which biological samples were collected. Until now this two datasets were kept separately and any intention of mapping the appearance of a certain organism or taxa group was done thru a long time process of selection of queries, generally used for the intended purpose and discarded later.

The Colombian Caribbean Marine Biodiversity Geodatabase designed in the frame on this research, allows doing integration between taxonomical records and their associated collection point along the study area. Individual species representation or even more complex queries such as taxonomical aggregations, are now easily obtained and saved for future reference. This achievement alone is an example of how GIS can aid the conversion of abstract tag locations into simpler map representations. All the capabilities of the GIS can help to manage and obtain additional information from different sources besides the collected with the sample alone. The only measure taken with the macrobenthic dataset at each sampling point was depth. By overlaying this macrobenthic dataset to other data covers such as the geological provinces, the ecoregions distribution or benthic habitats, we were able to associate these communities with the environment in a more comprehensive way.

There is certainly a lot of work that still needs to be done in the Geodatabase to make it fully functional. The ArcGIS Marine Data Model used as a template[46]., has powerful capabilities for the management of natural as well as man made features that were not exploited. However, this example sets the basis into the development of similar GIS that help to support systematic conservation planning as well as similar initiatives. Because of the ever changing state of a complex system such as the marine one, we certainly could take advantage of GIS flexibility into developing dynamic scenarios that improve site selection process over time.

If an actual site selection for biodiversity conservation purposes would be made over any area of the continental Caribbean of Colombia, the management of information would certainly be a point of concern. The situation encountered in this research could become even worst when trying to manage environmental datasets of many different agencies/organizations with a wide disparity on the area coverage, the level of detailed and the currency of the data. Moreover, the site selection process relays not only on ecological sources of information. Economical and cultural criteria among others need to be address in the same dimension as the area of interest. More attention should then be given to data standards, including metadata and quality assessment of the original source data. Collected data should always tried to be provided and collected with error estimates and users should give attention to the propagation of error from the initial data collection through each stage of the analyses carried out [72].

This example reflects the need to invest into the development of a unified spatial information platform that supports biodiversity conservation planning regardless of the area of interest. The development of a GIS that allows easy manipulation of data enhances the potential for management agencies to integrate marine and adjacent terrestrial systems into decision making [42]. Using common structures facilitate the production, share and exchange of data in similar formats. If such a structure is adopted into future researches, although not strictly focused for conservation planning, will certainly add supporting elements to the process dealing more effectively with scale dependencies [11, 18].

The need to focus on small areas for national conservation is as important as having a big picture of Colombian goals into the continental or even global context. Coral reefs for example, are transboundary resources and it is at these larger regional scales that integration and standardisation is needed to facilitate the conjunction with regional management initiatives towards its conservation initiatives [10]. On the other hand focusing the attention on protecting a sample of each ecoregion for example, will certainly miss elements of biodiversity that respond to biophysical features at a finer scale.

Luckily enough, in the study we counted on species information but it is very unlikely that for an actual site prioritization it would be relayed on this level of detail. One way of abording this problem is to predict the wider spatial distribution patterns by modelling the probable distribution of surrogates in areas that have not been systematically surveyed. This research used generalized regression analysis for the spatial prediction from sparsely macrobenthic assemblages data points. These methods need to develop a statistical relationship between a variable of interest (species distribution) and the environmental descriptors [66].

Although this relation between the assemblages and the selected descriptors was tested positively, the prediction was done under an inductive approach; the ecological requirement of the assemblages were derived from the locations were they occurred. This could be seen as a proper approach when lacking of additional environmental information. However the prediction of the surrogated done this way may not define confidence intervals of these predictions neither the relative importance that predictors had over one and other.

Depth seemed like a strong explanatory variable for the definition of macrobenthic species assemblages as generally recognized for this type of communities in the area. Communities inhabiting shallower waters seem closest related that those from depth waters. My own experience on the infaunal community of the closest area to Santa Marta and Bocas de Ceniza, seemed to reflect the same response to depth gradient. It also seems to be a strong relation between the macrobenthos and sediment type. Although the sedimentary fascies distribution along the Caribbean was available, this was only described up to -200 m and thus not used as a common factor defining the distribution of the assemblages. The use of the distance to the river as a disturbing factor of the sediment dispersion along the area intended to reflect this spatial variability. In the same way, the use of the distance to the benthic habitat (coral reefs and sea grasses) accounted for the differentiation of a possible spatial zonation of the area. The selection of these parameters do not imply an explanatory ecological relation with the macrobenthic assemblages, but an inductive assumption of concurrence to similar predictors over the area.

The ecological analysis presented herein was the first attempt of compiling all the species taxa from the surveys into a unified assessment. Previous community analysis had been based solely on one phylum (and unfortunately, only described in grey literature). As a general consensus these analysis show that the assemblages and the abundances of the species vary along the Caribbean platform, apparently sub diving it into three zones: the north (GUA and PAL ecoregions) the Tayrona (TAY) and the area south of this ecoregion. The turning point of this division seems to be the influence of the sedimentary plume of the Magdalena River.

This pattern is only consistent with five of the nine defined macrobenthic assemblages of this research. *Penaeopsis serrata-Gaza olivacea* is only present on the TAY region and in some extent *Penaeopsis serrata-Parapeneus politus* and *Mulinia cleryana-Trachycardium muricatum* seem to be associated to this same system. Almost exclusively associated to the north sector of this region is *Glyphocrangon neglecta-Hyalinoecia artifex* and towards the south is *Munida longipes-Neobythites gilli*. The other assemblages (4, 5, 6 and 9) seem to be distribute along the hole platform but with the difference that *Portunus spinicarpus-Macoma tenta,* is restricted to shallower waters.

The macrobenthic assemblage predicted distribution maps appeared consistent with the observed distribution of the sampling points. *Portunus spinicarpus-Macoma tenta* assemblage was predicted with the largest distribution (23.% coverage of the total area), followed by *Glyphocrangon neglecta-Prionocrangon pectinata* and *Portunus spinicarpus-Citharichthys cornutus* (10% and 7.1% coverage respectively); this last one also seem to have the widest prediction distribution of all. *Penaeopsis serrata-Parapeneus politus* covering the smallest area among all the assemblages (2%) was predicted on very speckled areas. *Mulinia cleryana-Trachycardium muricatum* on the other hand appeared with a comparative and compact short range distribution localized southern Ciénaga Grande de Santa Marta.

The inductive way of doing the modelling of these distributions calls for caution into its interpretation. These model should always be supported on validation, that could'n be done within this research. Moreover, the distribution representations do not account for the species mobility giving a static description. All this assumptions are implicit when using these models and thus needed to be accounted when incorporated into any decision making process.

Nevertheless, the spatial distribution of the macrobenthic assemblages is based on the best current knowledge and provides an insight into the presence of the species composing the assemblages in the Colombian Caribbean area. This method was useful to identify spatial patterns althoug recognizing the limitation in the interpretation of its results. The distribution for the macrobenthic assemblages were based on the statistical methods rather than the analysis of the environmental factors influencing them. Even thou, these models can be considered as powerful tools for gaining ecological insight or guiding management activities [48, 66, 73, 74]. The high quality requirements of these models, constrain the quality of the results. This characteristic on the other hand allows to explore their potential on aiding the identification of data outlines and needs for new data collection based on adequate sampling strategies [66]. It is this potential in the marine environment that could be further exploited. If the site selection process were to be done on key species, it would be more appropriate to base their distribution prediction on the knowledge of their ecological requirements before attempting statistical approaches.

The selection of sites that have been included in the National Natural Park System of Colombia has generally been defined using surrogates such as ecosystems rather than using finer scale surrogate measures. As suggested by several authors [5, 11, 42, 75] the development of appropriated surrogate measures at a finer scale (e.g. habitat) will likely increase the possibility of adequately achieve biodiversity conservation objectives by ensuring protection of greater range of habitats and species.

Thus, in the initial site selection process, categories of information such as the number of species and genera present in a given area as well as the migratory and feeding patterns and ranges of key or threatened species may be helpful. Although empirically treated in this research throughout the use of the distance to benthic habitats as a way to consider the extent and spatial scale of population connectivity, careful consideration on this issue should be made if marine reserve areas are meant to be supporting fishery management tools [20].

An important lesson learned from this research came from the exploration of appropriated biodiversity surrogates for the site selection process. Although the main driving force for the surrogate's selection was the availability of information, the use of macrobenthic assemblage's data ended in a fair judgment. To give support to this decision a comparison on the total number of species that were included into defined selected site could have been done as suggested by Vanderklift *et al*., (1998), but skipped because of time constrains.

Based solely on biological criterion we were able to identify locations that are now under consideration for boundary extension by the NNPS. The southern region of the Islas del Rosario National Park (Islas de San Bernardo) was consistently selected as a representative site of the biodiversity surrogates. This sector as well as the Santa Marta and Guajira holded 50% of the total species collected in the MacroI survey defining these areas as hot spots of biodiversity. The finding of deep-sea corals formations around these Islands has justified the formulation of a research towards extending this Park boundary. It is expected that the methodological framework applied in the regional context in the research, could find a follow up trial in this local case study.

Some other areas such as Guajira and Uraba regions lacking today from formal protection are also being considered as key areas ond potencialy considered . These areas were also highlighted by the MARXAN site selection. A number of important sites are identifiable as key component for representing the selected marine biodiversity surrogates. A generally sparse distribution of sites selected throughout the study area by the two problem scenarios was observed.

Of particular interest are the regions around the Guajira (Riohacha and Manaure) the Bahia de Santa Marta, Islas de San Bernardo and Uraba adjacent to some terrestrial reserves that exist in this region. High concentrations of selected sites are found in the deep-water regions between Bocas de Ceniza and Cartagena. A noticeable linear selection is found throughout most of the solutions, running north-south on the deep zone. Most of the macrobenthic assemblage's datasets have similar distribution in these areas and it is possible that sites selected in these areas have selected different feature within this same sites.

A number of adjacent PU are selected along the Santa Marta region this phenomenon could be explained due to the wide variety of features contained within a small area, making these sites more attractive for selection when running the algorithm. A distinct absence of selected sites occurs in the northern-central region, directly north-west of Salinas de Manaure and north-east Golfo de Morrosquillo. These regions have relatively homogenous environments with little feature representations. Although it doesn't mean that they don't contribute of the whole area. Thus, these regions do not contribute greatly to the biodiversity representation. This last statement however doesn't imply that they shouldn't be considered as potential conservation sites as will be discussed in the following section.

A clumped distribution of sites north of Bocas de Ceniza and a scattered distribution south of Golfo de Morrosquillo can be generally compared in the solution for both scenarios. The use of fixed marine reserves (NNPS areas) certainly increases the number of PU around these areas to meet the same target goals, reducing the representation of conservation features in areas highlighted by the identified in the *No reserve* scenario.

A long process will have to be carried on before any of the highlated areas could even be considered in a prioritization proceadure. Is fare to emphasize at this point that, the results of this research should not be used to infer any implication about conservation policy. There is no reason to suppose that the selected surrogates are adequate enough to represent the marine biodiversity of the study area. At the very best, if we are solely concerned with a population dependant of macrobenthic conservation, the results obtained indicate a direction in which further analysis should go. Following the aim of the study to advocate a systematic and objective approach to site selection based solely on biodiversity contents the template of a regional scheme, rather than providing a definitive solution was presented.

The use of assemblages as surrogates for species richness identified and derived from taxonomic levels higher that species and similar representation into selecting representative marine areas could be seen a follow up consideration. The representation of endemic, rare and migratory species is important in site selection, as are areas of high productivity, spawning areas, nursery areas and feeding grounds. It must be recognized that areas important for these reasons may not be included in sites selected solely on the basis of taxon diversity. Neither are the considerations of the treats triggering the need of protecting these species.

As suggested by Margules and Pressey (2000) more effort is needed to map patterns and monitoring rates of spreading threats to biodiversity, as it is such threats to which conservation planning should respond. This kind of information on vulnerability or threat can be used to help set the targets of a priority site selection procedure. Because the limiting resources invested into the NNPS preference should be given to those sites both vulnerable and making important contributions to the conservation goal.

Under the several acts defining the extent of the NNPS, this boundary is generally extend to an arbitrary bathymetric contour and therefore includes the soft bottom ecosystems. However, there has been no attempt to estimate the extent of the potential impact of numerous human activities, forcing the failure to protect representative examples of Colombian soft bottom benthic features. The validity of using the benthic biodiversity surrogates described in this document is subjected to follow up research assessing the design of a benthic system that meets the goals of biodiversity conservation.

At present, there is not sufficient information to determine a target percentage of protection required for conservation features used to ensure adequate protection of biodiversity. The formulation of conservation targets for biodiversity pattern and process in the Caribbean Region of Colombia is still an explored initiative and far beyond the scope of this research. It is a fact that Colombians in general have turned their back to the 50 % of the underwater national territory and thus it is reveal in the little knowledge that we have on the actual state of our waters. In this research, a minute reflection of its biodiversity was made leaving a huge trace for further development.

As mentioned earlier systematic planning for conserving biodiversity is a dynamic process and thus needs to rely on the scale and time frame in which decisions are taken. In this research we intended to give a general framework for the site selection framework for conserving marine biodiversity using a vast area of the Colombian territory. It is not intended that the results give a prioritization of areas at this scale, just a general pattern of how simple and accessible tools could be used to support this process in more detailed and particular cases.

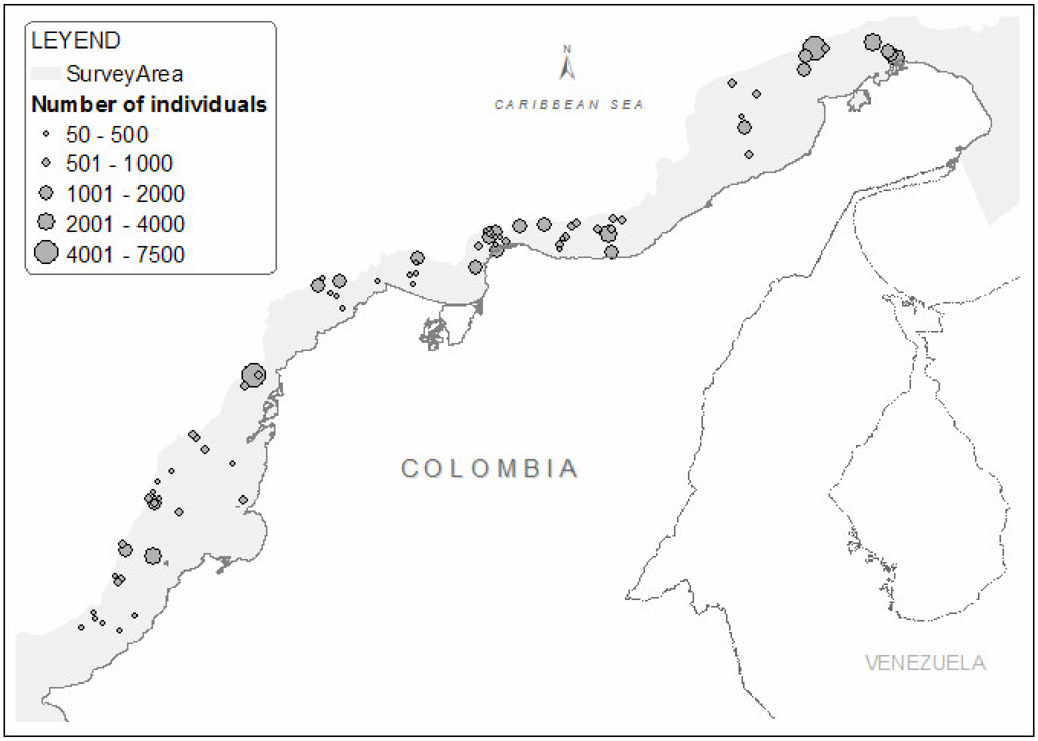
APPENDICES

Appendix 1. Stations of macrofauna at the Caribbean Coast of Colombia with sampling date, depth in meters, ecoregion, n. ind.= number of individuals per station, n.spp= number of species per station, D=Margalef's diversity, J'= Pielou's evenness, H'(loge) =Shannon's diversity, 1-Lambda'= Simpson's diversity.

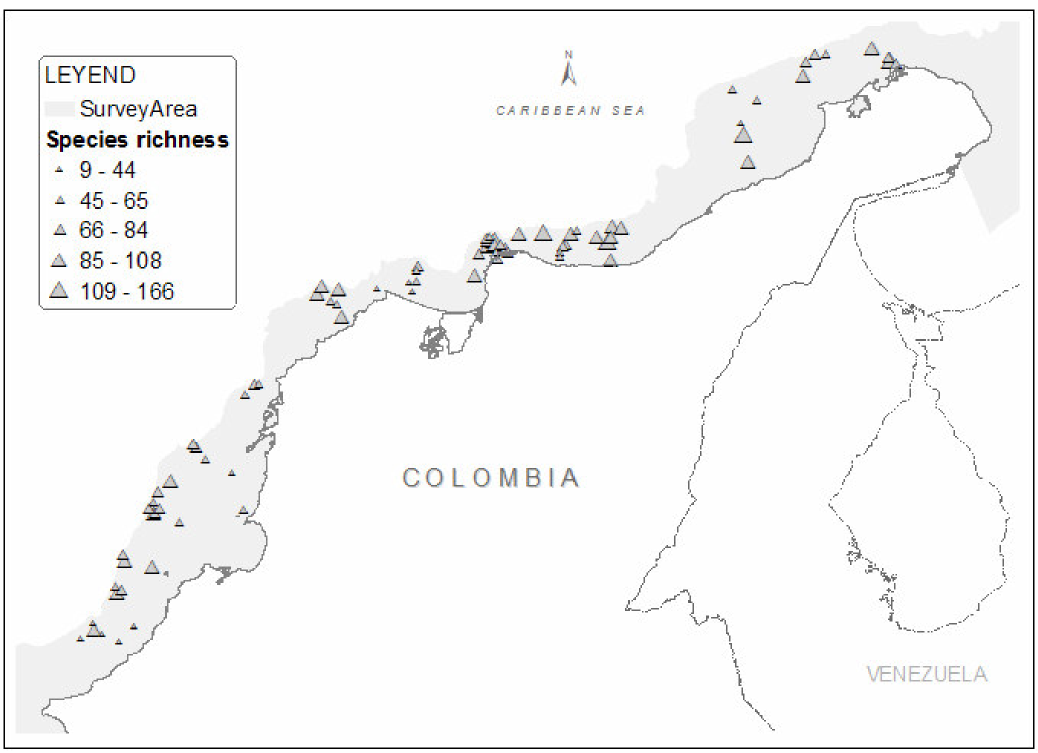
Station	*Date*	*Depth*	*Ecoregion*	*n. ind*	*n spp.*	*D*	*J'*	*H'(loge)*	*1-Lambda'*
INV 022	02-Oct-98	409	MAG	332	55	11.59	0.676	3.041	0.907
INV 023	02-Oct-98	207	MAG	357	48	7.63	0.133	0.565	0.160
INV 018	03-Oct-98	403	TAY	246	62	8.38	0.764	3.061	0.928
INV 019	03-Oct-98	219	TAY	1115	124	10.44	0.437	1.908	0.573
INV 001	19-Nov-98	303	GUA	2156	90	13.11	0.736	3.337	0.925
INV 002	21-Nov-98	457	GUA	7419	69	9.12	0.694	2.864	0.904
INV 003	22-Nov-98	444	GUA	1761	79	8.92	0.610	2.508	0.765
INV 004	22-Nov-98	300	GUA	1118	93	12.99	0.740	3.313	0.924
INV 005	24-Nov-98	466	GUA	802	62	12.85	0.687	3.076	0.876
INV 006	24-Nov-98	307	GUA	832	61	14.00	0.767	3.469	0.937
INV 007	25-Nov-98	482	PAL	812	88	15.36	0.808	3.743	0.958
INV 008	25-Nov-98	299	PAL	873	88	12.61	0.806	3.520	0.949
INV 009	26-Nov-98	309	PAL	666	92	12.04	0.642	2.822	0.837
INV 010	26-Nov-98	498	PAL	766	103	15.85	0.765	3.617	0.952
INV 011	27-Nov-98	296	PAL	485	79	12.96	0.591	2.666	0.778
INV 012	27-Nov-98	490	PAL	1173	113	16.30	0.784	3.713	0.953
INV 013	01-Dec-98	505	TAY	1037	91	13.06	0.632	2.828	0.803
INV 014	02-Dec-98	305	TAY	1026	114	11.96	0.798	3.412	0.934
INV 015	02-Dec-98	297	TAY	783	88	11.73	0.615	2.711	0.874
INV 016	02-Dec-98	497	TAY	378	72	11.08	0.838	3.457	0.943
INV 017	03-Dec-98	494	TAY	998	82	17.53	0.628	3.028	0.858
INV 020	04-Dec-98	467	MAG	1277	74	10.21	0.582	2.503	0.828
INV 021	04-Dec-98	275	MAG	1269	88	12.17	0.485	2.172	0.676
INV 026	06-Dec-98	319	MAG	1005	100	9.30	0.671	2.689	0.845
INV 027	06-Dec-98	277	MAG	621	64	8.00	0.702	2.716	0.884
INV 024	07-Dec-98	491	MAG	439	87	14.13	0.661	2.951	0.838
INV 025	07-Dec-98	502	MAG	1138	94	13.22	0.728	3.308	0.920
INV 038	08-Apr-99	511	ATR	258	41	14.32	0.698	3.214	0.914
INV 039	08-Apr-99	298	ATR	331	88	9.80	0.541	2.250	0.732
INV 036	09-Apr-99	495	ATR	343	63	12.54	0.809	3.554	0.951
INV 037	09-Apr-99	314	ATR	560	96	12.76	0.793	3.505	0.944
INV 034	10-Apr-99	498	ATR	623	82	14.97	0.744	3.363	0.912
INV 035	10-Apr-99	298	ATR	1355	87	14.23	0.913	3.979	0.978
INV 031	13-Apr-99	523	ARCO	224	78	9.68	0.826	3.310	0.941
INV 032	13-Apr-99	483	ARCO	264	55	10.86	0.635	2.715	0.809
INV 033	13-Apr-99	285	ARCO	507	91	14.45	0.775	3.494	0.929
INV 030	14-Apr-99	270	ARCO	436	92	11.38	0.599	2.633	0.835
INV 028	15-Apr-99	474	ARCO	589	81	12.59	0.699	3.082	0.896
INV 029	15-Apr-99	302	ARCO	617	83	11.93	0.477	2.131	0.679
INV 040	14-Mar-01	22	GUA	2571	81	10.62	0.858	3.555	0.961
INV 041	14-Mar-01	72	GUA	1822	122	15.01	0.804	3.669	0.947
INV 042	14-Mar-01	150	GUA	1674	82	7.20	0.836	3.103	0.940
INV 002B	15-Mar-01	496	GUA	627	55	14.99	0.874	3.912	0.971
INV 043	15-Mar-01	151	GUA	287	35	10.19	0.684	3.007	0.914
INV 045	15-Mar-01	70	GUA	1571	135	16.12	0.598	2.874	0.870
INV 046	16-Mar-01	22	GUA	962	108	10.91	0.636	2.803	0.888
INV 047	17-Mar-01	153	PAL	859	86	6.01	0.661	2.349	0.857
INV 048	17-Mar-01	72	PAL	2854	166	18.21	0.759	3.724	0.955
INV 049	17-Mar-01	21	PAL	1124	89	15.58	0.700	3.278	0.912
INV 011B	18-Mar-01	300	PAL	768	81	12.58	0.616	2.744	0.856

Station	*Date*	*Depth*	*Ecoregion*	*n. ind*	*n spp.*	*D*	*J'*	*H'(loge)*	*1-Lambda'*
INV 050	18-Mar-01	71	PAL	458	59	20.74	0.614	3.136	0.867
INV 051	18-Mar-01	152	PAL	563	64	12.53	0.635	2.852	0.863
INV 052	18-Mar-01	504	PAL	625	53	9.47	0.853	3.478	0.959
INV 054	19-Mar-01	20	TAY	595	84	9.95	0.714	2.970	0.902
INV 055	19-Mar-01	76	TAY	582	87	8.08	0.697	2.767	0.863
INV 056	19-Mar-01	151	TAY	489	76	12.99	0.781	3.462	0.939
INV 057	19-Mar-01	154	TAY	458	86	13.51	0.806	3.600	0.960
INV 058	19-Mar-01	72	TAY	406	57	12.11	0.808	3.498	0.947
INV 059	19-Mar-01	40	TAY	1306	74	13.87	0.804	3.581	0.950
INV 061	21-Mar-01	20	MAG	239	36	9.32	0.796	3.218	0.937
INV 062	21-Mar-01	70	MAG	281	40	10.17	0.655	2.818	0.844
INV 063	21-Mar-01	153	MAG	50	9	6.39	0.792	2.838	0.901
INV 064	22-Mar-01	21	MAG	387	93	6.92	0.821	3.029	0.937
INV 065	22-Mar-01	72	MAG	331	48	2.04	0.911	2.002	0.869
INV 066	22-Mar-01	150	MAG	279	58	15.44	0.779	3.529	0.925
INV 067	23-Mar-01	309	MAG	965	65	8.10	0.678	2.625	0.803
INV 068	23-Mar-01	510	MAG	4294	76	10.12	0.810	3.290	0.941
INV 071	24-Mar-01	150	ARCO	826	56	9.31	0.514	2.146	0.670
INV 032B	25-Mar-01	514	ARCO	689	72	8.97	0.343	1.487	0.571
INV 033B	26-Mar-01	270	ARCO	1129	81	8.19	0.794	3.197	0.944
INV 072	26-Mar-01	71	ARCO	493	38	5.97	0.717	2.607	0.877
INV 072B	26-Mar-01	71	ARCO	731	59	8.80	0.776	3.162	0.940
INV 073	26-Mar-01	160	ARCO	385	75	12.43	0.787	3.398	0.943
INV 074	29-Mar-01	22	MOR	3048	103	12.71	0.671	3.112	0.904
INV 075	29-Mar-01	160	ATR	757	78	11.61	0.782	3.408	0.940
INV 076	29-Mar-01	150	ATR	168	43	8.20	0.872	3.279	0.947
INV 077	29-Mar-01	70	ATR	138	27	5.28	0.803	2.645	0.894
INV 078	30-Mar-01	21	ATR	54	14	3.26	0.849	2.241	0.875
INV 079	30-Mar-01	20	ATR	312	44	7.49	0.722	2.733	0.900
INV 080	31-Mar-01	20	MOR	539	48	7.47	0.726	2.812	0.901

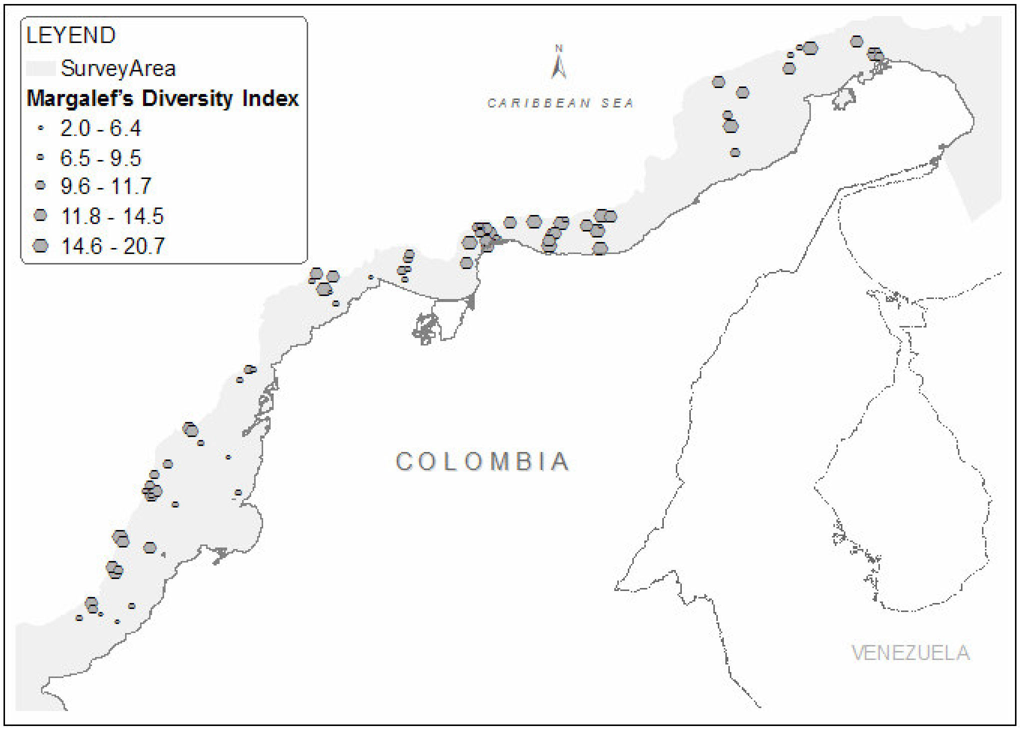
Appendix 2. Map representing the sedimentary fascies of the Colombian Caribbean.



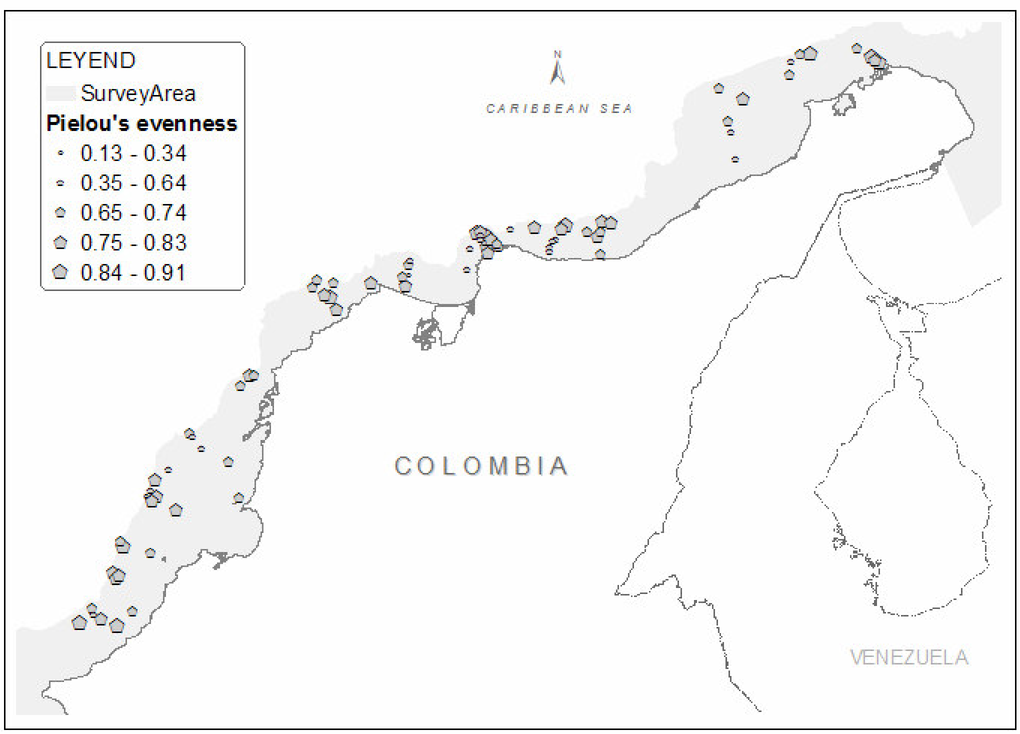
Appendix 3. Observed distribution of the number of individuals collected in the MacroI and MacroII surveys along the Caribean Region of Colombia..



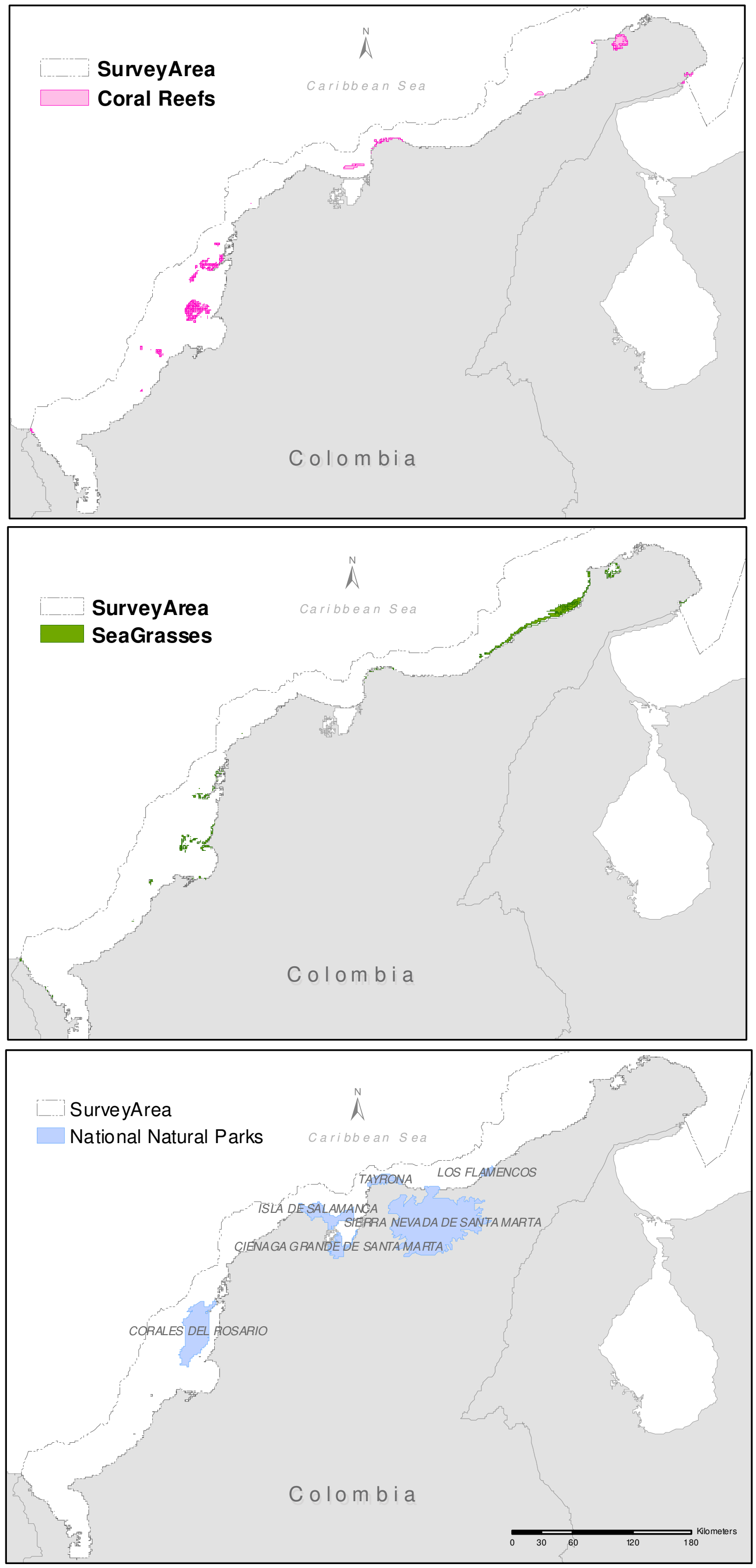
Appendix 4.Observed distribution of the species richness deduced from the analysis of the macrobenthic data collected during the MacroI and MacroII surveys.



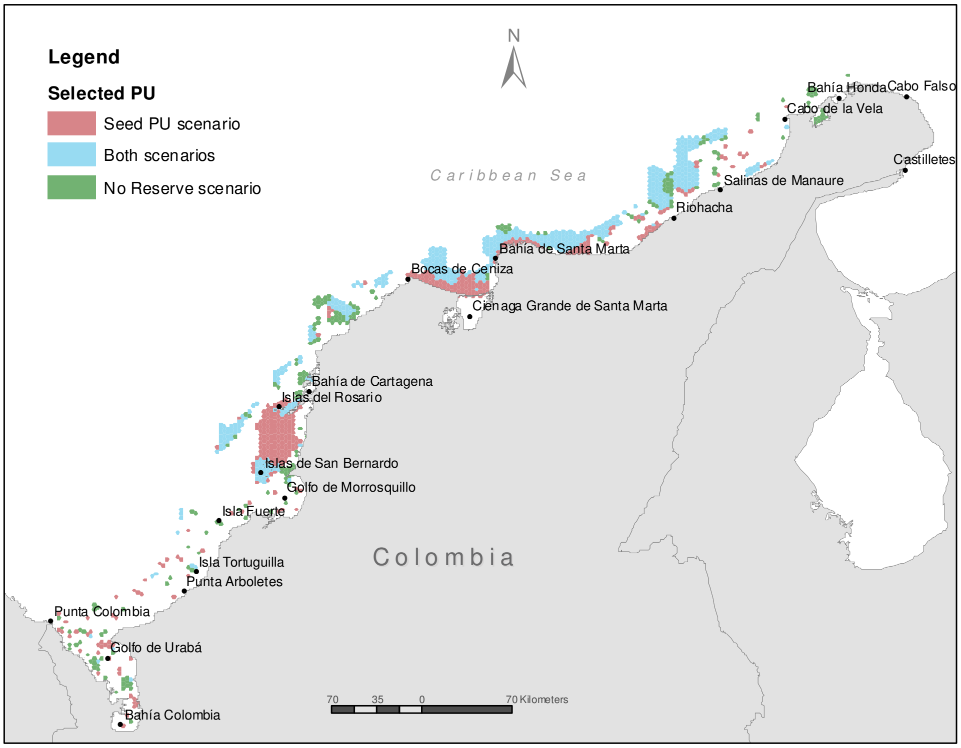
Appendix 5. Observed distribution of the Margalef's diversity Index deduced from the analysis of the macrobenthic data collected during the MacroI and MacroII surveys.



Appendix 6. Observed distribution of the Pielous evenness Index deduced from the analysis of the macrobenthic data collected during the MacroI and MacroII surveys.



Appendix 7. Spatial distribution of the conservation features beside the macrobenthic assemblages used for the site selection process in MARXAN.



Selected PU for the *Seed PU* represented in red and *No reserve* scenario represented in green. The planning units selected by both scenarios are represented in blue.

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