SIMAC: Development and implementation of a coral reef monitoring network in Colombia

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Abstract: Significant coral reef decline has been observed in Colombia during the last three decades. However, due to the lack of monitoring activities, most of the information about health and changes was fragmentary or inadequate. To develop an expanded nation-wide reef-monitoring program, in 1998 INVEMAR (Instituto de Investigaciones Marinas y Costeras: "Colombian Institute of Marine and Coastal Research") designed and implemented SIMAC (Sistema Nacional de Monitoreo de Arrecifes Coralinos en Colombia: "National Monitoring System of Coral Reefs in Colombia") with the participation of other institutions. By the end of 2003 the SIMAC network reached more than twice its initial size, covering ten reef areas (seven in the Caribbean and three in the Pacific), 63 reef sites and 263 permanent transects. SIMAC monitoring continued without interruption until 2008 and should persist in the long-term. The SIMAC has a large database and consists basically of water quality measurements (temperature, salinity, turbidity) and a yearly estimation of benthic reef cover, coral disease prevalence, gorgonian density, abundance of important mobile invertebrates, fish diversity and abundance of important fish species. A methods manual is available in the internet. Data and results of SIMAC have been widely circulated through a summary report published annually since 2000 for the Colombian environmental agencies and the general public, as well as numerous national and international scientific papers and presentations at meetings. SIMAC information has contributed to support regional and global reef monitoring networks and databases (i.e. CARICOMP, GCRMN, ReefBase). Rev. Biol. Trop. 58 (Suppl. 1): 67-80. Epub 2010 May 01.

Key words: coral reefs, monitoring, SIMAC, GCRMN, Colombia.

Colombia is the only South American country with Caribbean (1 700km) and Pacific (1 300km) coasts and coral reefs. Nevertheless, coral reef development is limited in Colombia due to the scarcity of hard bottoms, the dominance of sedimentary environments, the presence of large rivers and the influence of upwelling waters in some areas (Prahl & Erhardt 1985, Wells 1988, Garzón-Ferreira 1997). There are about 2 800km^2 of coral reef environments within Colombian waters in the Caribbean, sparsely distributed among 26 discrete areas (Díaz *et al.* 2000a, Garzón-Ferreira & Díaz 2003). These areas can be divided according to their location and ecological features in three main regions: (a) the mainland coast with fringing reefs along metamorphic or volcanic rocky shores, such as the Santa Marta and Urabá areas; (b) reefs growing on the continental shelf around offshore islands, such as the Rosario and San Bernardo archipelagos; and (c) the oceanic reef complexes of the San Andrés Archipelago in the Western Caribbean (Fig. 1). The latter are the best-developed coral formations, including atolls, banks, barrier reefs, fringing reefs and patch reefs, and account for more than 75% of the coral reefs areas in Colombia (Díaz *et al.* 2000a). Reef development along the Pacific coast of Colombia is in contrast insignificant, Gorgona Island being the only place exhibiting extensive coral formations (Glynn *et al.* 1982, Zapata 2001,

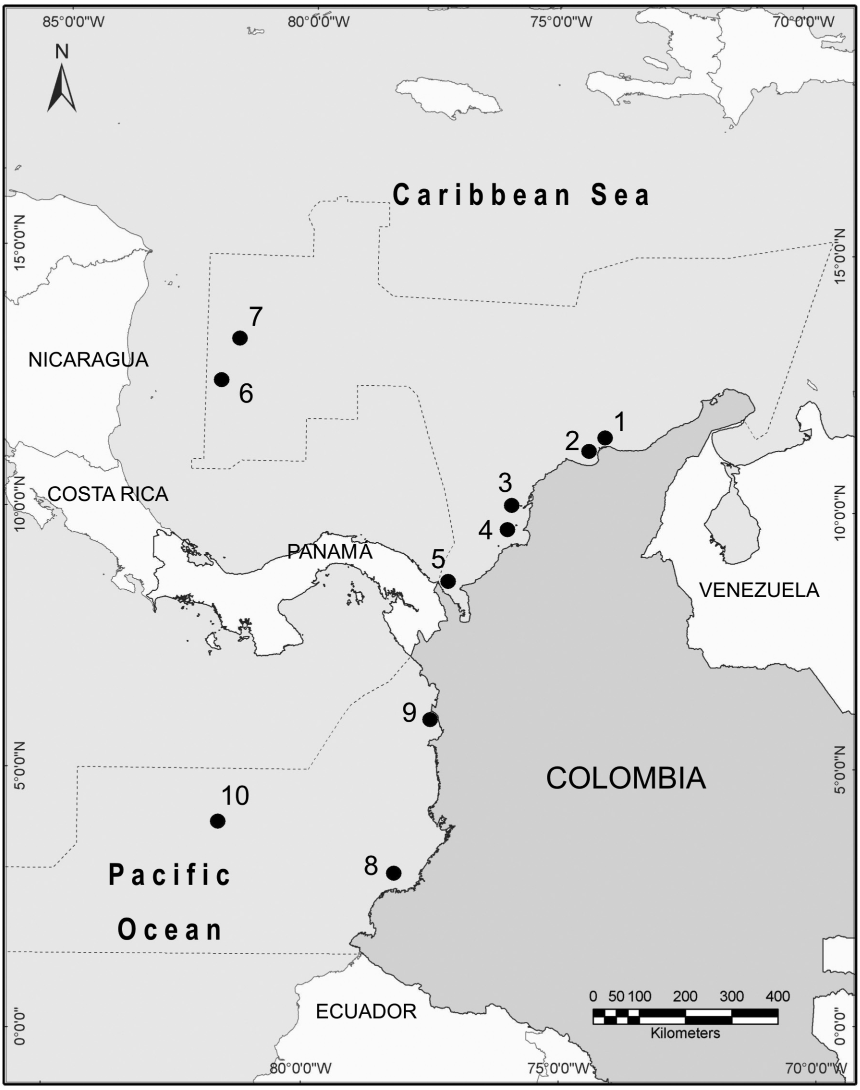

Fig. 1. Location of SIMAC monitoring reef areas in the Caribbean and Pacific territories of Colombia: 1) Tayrona Natural Park; 2) Santa Marta bay; 3) Rosario islands; 4) San Bernardo islands; 5) Urabá area; 6) San Andrés island; 7) Providencia island, 8) Gorgona island; 9) Utría bay; 10) Malpelo island.

Zapata &Vargas-Ángel 2003). There are a few reef patches also in Ensenada de Utría and the oceanic Isla de Malpelo, which is 350km off the coast and has coral communities down to 35m depth (Vargas-Ángel 1996, Garzón-Ferreira & Pinzón 1999, Zapata & Vargas-Ángel 2003). Around 60 hard coral species are known from the Caribbean, and 21 from the Pacific (Prahl 1985, Díaz *et al.* 2000a, Zapata & Vargas-Ángel 2003).

Significant coral reef decline has been observed in Colombia during the last three decades, as in many reefs worldwide. Reefs in the Pacific coast suffered high levels of coral mortality after the 1983 ENSO-related strong bleaching event (Prahl 1985, Glynn 1990). In the Caribbean coast, numerous reef areas have shown evidence of diverse perturbations like reduction of live coral cover, mass mortalities of corals and other invertebrates, algae proliferation, coral diseases and overfishing, especially during the eighties (Garzón-Ferreira & Kielman 1994, Garzón-Ferreira 1997). However, due to the lack of monitoring activities, most of the information about health and changes was fragmentary or inadequate, so that reef degradation processes were not well documented and their causes poorly understood. In order to assess the origins, extent and progress of this degradation and to provide recommendations for coral reef management in Colombia, the "Instituto de Investigaciones Marinas y Costeras (INVEMAR)" has carried out several projects during the last decade to develop a long-term national reef monitoring program. In this introductory paper we will show how we have organized and continue to operate this program, and describe the basic SIMAC protocols and monitoring sites that are referred to in several subsequent papers about Colombian reefs within this issue.

The origin and development of SIMAC

In Colombia, reef monitoring began towards the end of 1992 when INVEMAR joined the CARICOMP (Caribbean Coastal Marine Productivity) program and implemented a permanent monitoring site in Chengue Bay on the Caribbean coast. Since then, water quality and bottom community measurements have been done without interruption at two coral stations but also on seagrass and mangrove stations (Garzón-Ferreira 1999, Rodríguez-Ramírez & Garzón-Ferreira 2003, Linton & Fisher 2004). Based on the experience gained with CARICOMP and with the purpose of developing an expanded nation-wide reef-monitoring program, in 1998 INVEMAR designed and implemented SIMAC ("Sistema Nacional de Monitoreo de Arrecifes Coralinos en Colombia"), with the support of COLCIENCIAS and several other Colombian institutions (CORALINA, UAESPNN, CEINER, Universidad del Valle, and Universidad Nacional). During this first stage, the SIMAC installed and assessed monitoring stations at four coralline areas in the Caribbean (San Andrés Island, Santa Marta Bay, Tayrona Natural Park and Rosario Islands) and one in the Pacific (Gorgona Island)(Fig. 1).

Afterwards, more monitoring stations have been added progressively with the collaboration of additional institutions (MAVDT, UNEP-RCU/CAR, Universidad de Antioquia), so that in 2003, the SIMAC network reached more than twice its initial size, covering ten reef areas (seven in the Caribbean and three in the Pacific), 63 reef sites and 263 permanent transects. The additional areas are Providencia Island, San Bernardo Islands and Urabá area in the Caribbean, and Utría Bay and Malpelo Island in the Pacific (Fig. 1). SIMAC monitoring continued without interruption until 2008 and should continue indefinitely as the system is considered one of the long-term strategic projects at INVEMAR with regular support from the Ministry of the Environment of Colombia.

The organizational structure of SIMAC is similar to that of CARICOMP (Fig. 2). There is a National Coordinating Institution (NCI) which is in charge of the program management and the negotiation of the Memorandum of Understanding (MOU) with the Local Coordinating Institutions (LCI). Currently, the NCI is INVEMAR, which was selected by the LCIs since the beginning of the program and was ratified during the first annual Assembly in 2004. The MOU specifies the responsibility of each institution to the network, including the nomination of a Site Director. A LCI is responsible for getting support and implementing the SIMAC protocol in selected reef areas. At present, there are four LCIs that have signed a MOU with INVEMAR: (1) CORALINA for San Andrés and Providencia islands, (2) UAESPNN for Rosario and San Bernardo islands, (3) Universidad del Valle for Gorgona Island, and (4) Universidad de Antioquia for

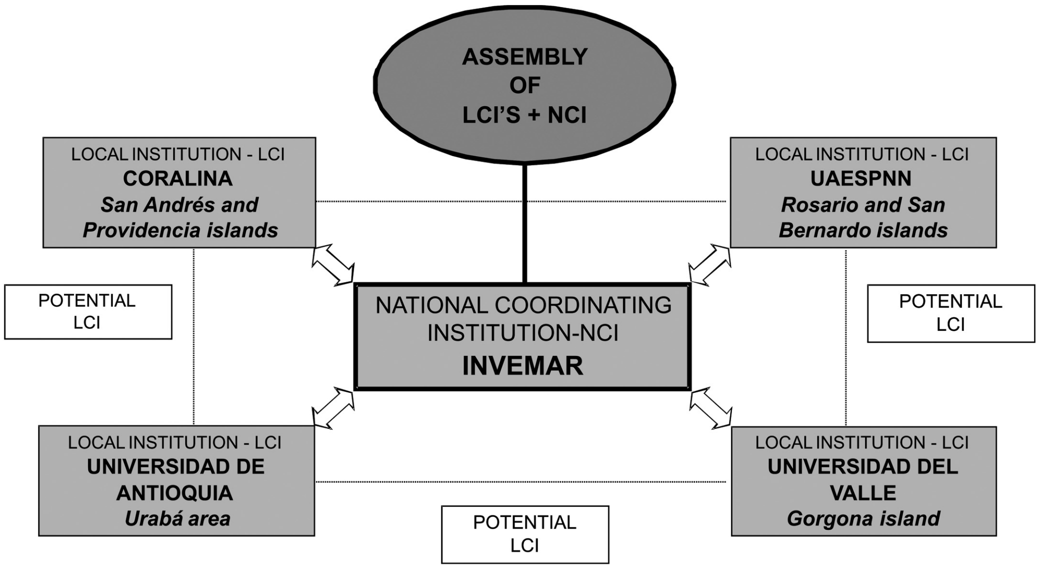

Fig. 2. Schematic model of the organizational structure of SIMAC.

the Urabá area. Nevertheless, none of these institutions have been able to carry out the SIMAC protocol independently and had to receive funding and/or technical support every year from the NCI.

The development of a database is one of the fundamental tasks that ensure that the monitoring information is useful for the scientific community. One such database was created and named SISMAC (Information and Support System for Coral Reef Monitoring in Colombia) which is located at INVEMAR. The database is organized on an Oracle 8.1.7 platform and includes special systems for data storage and query that can be accessed through internet. The query system allows the examination of raw data but also provides some basic statistics (means, standard errors) and graphics. An Oracle tool and a manual (Arias 2002) for direct data storage and query have been provided to the institutions in Colombia which are participating in the SIMAC program.

Data and results of SIMAC have been widely circulated through a summary report published annually since 2000 for the environmental management agencies and the general public in Colombia (i.e. Garzón-Ferreira & Rodríguez-Ramírez 2001, Rodríguez-Ramírez *et al.* 2005), as well as the publication of nearly 30 scientific papers (i.e. Garzón-Ferreira & Pinzón 1999, Garzón-Ferreira & Díaz 2000, 2003, Garzón-Ferreira *et al.* 2001, Gil-Agudelo & Garzón-Ferreira 2001, Mejía-Niño & Garzón-Ferreira 2003, Rodríguez-Ramírez & Garzón-Ferreira 2003, Weil *et al.* 2003, Reyes-Nivia *et al.* 2004) and the presentation of more than 25 talks in national and international meetings (i.e. Bejarano *et al.* 2006, Rodríguez-Ramírez *et al.* 2006). Also, SIMAC information has contributed to support regional and global reef monitoring networks and databases. INVEMAR is a member of the CARICOMP network since its origin and has been able to maintain the monitoring activities in Chengue Bay without interruption during several years thanks to SIMAC assistance (Linton & Fisher 2004). The SIMAC team also promoted the organization of Reef Check activities during some years in Colombia and has made contributions to the Global Coral

Reef Monitoring Network (GCRMN) with the support of UNEP-RCU/CAR. It coordinates a regional node of the GCRMN for the Southern Tropical America (Costa Rica, Panamá, Colombia, Venezuela and Brazil) and has been involved in the preparation of reports for the global assessments of coral reefs (Garzón-Ferreira *et al.* 2000, 2002a, 2004). These and other reports, as well as CARICOMP data, have been submitted to the global database for coral reefs (ReefBase).

Reef areas and monitoring sites

The ten reef areas for SIMAC monitoring (Fig. 1) were selected in order to include a wide representation of reef systems in Colombian waters. Those areas were chosen also by their facilities for carrying out fieldwork and their importance as tourist centers or natural reserves. In this section, we will provide a general description and information for six Caribbean monitoring areas and one from the Pacific, which are the areas that will be considered forward in several papers presenting SIMAC results within this special publication. Data on the geographic location, depth, type of coral assemblage (sensu Díaz *et al.* 2000a), the number of transects and monitoring years of each monitoring reef site (or plots) in these areas are presented in Table 1.

Caribbean

San Andrés Island (SAI): Is the main island of the oceanic archipelago of San Andrés and Providencia in the Southwestern Caribbean. It has been a traditional tourist and commercial center and supports a very high human population, so that, coral reefs are considerably affected at many places around the island (Zea *et al.* 1998). Reef development is significant in San Andrés and there are good descriptions about the evolution, geomorphology, structure and health of reefs and coral communities (Geister 1992, Díaz *et al.* 1995, Geister & Díaz 1997, Garzón-Ferreira & Díaz 2003). The six reef sites for SIMAC monitoring are located in the Southern portion of the leeward coast where human impact is low and fringing coral communities are well developed below six meter depth. The two shallow reef sites are placed at the shore terrace where the bottom is basically a bare pavement with sparse and small coral colonies mainly of *Siderastrea siderea*, *Agaricia agaricites* and *Diploria strigosa*. The two mid-depth reef sites are situated at the inner part of the intermediate reef terrace, near the sand channel that separates this terrace from the shallow one; the coral community there is more complex and compact, with *Montastraea annularis* as the dominant coral species followed by *Agaricia* spp., *M. faveolata* and *S. siderea*. The two deep sites are located near the outer margin of the intermediate terrace where reef surface changes to the reef slope; the morphology and composition of the coral community is similar to that of the mid-deep sites but dominated by *Montastraea franksi*.

Tayrona Natural Park (TAY): Is part of the Santa Marta area, which comprises about 80km of a basically rocky shoreline located near the central sector of the continental Colombian Caribbean (Garzón-Ferreira & Díaz 2003). Coastal topography is very complex and steep due to the proximity of the Sierra Nevada de Santa Marta, the highest mountain system of Colombia. The littoral rocky belt that extends underwater to 30m depth support poorly developed but diverse coral communities and fringing reefs (Werding & Sánchez 1989, Garzón-Ferreira & Díaz 2003).The area is seasonally affected by upwelling waters during dry months (December-March) and by continental runoff during rainy season (May-November). Chengue is a small bay in TAY where CARICOMP stations were established since 1992 (Rodríguez-Ramírez & Garzón-Ferreira 2003). The bay has no permanent human populations, but is frequently visited by fishermen and divers. Coral reef communities are poorly developed but diverse, and are concentrated as fringing reefs on the leeward shores of the bay (Garzón-Ferreira 1998), where the six permanent reef monitoring sites have been installed. One of the shallow reef

TABLE 1

Geographic location, depth range (in meters), type of coral assemblage (sensu Díaz et al. 2000a), number of transects and monitoring years of each monitoring reef site in seven SIMAC coral reef areas of Colombia

Reef site or plot	Code	Coordinates (N - W)	Depth (m)	Coral assemblage	Transects	Monitoring years
			CARIBBEAN			
San Andrés Island						
Wildlife shallow	WL-S	12° 30’ 47.28” - 81° 43’ 52.44”	4-5	Scattered corals on rock	5	98, 99, 00, 01, 02, 03, 04
Wildlife mid-depth	WL-M	12° 30’ 42.66” - 81° 43’ 57.9”	12	Mixed corals and gorgonaceans	5	98, 99, 00, 01, 02, 03, 04
Wildlife deep	WL-D	12° 30’ 47.8” - 81° 43’ 57.8”	16-18	Mixed corals and gorgonaceans	5	98, 99, 00, 01, 02, 03
Iguana shallow	IG-S	12° 30’ 1.5” - 81° 44’ 0.0”	5-7	Scattered corals on rock	5	98, 99, 00, 01, 02, 03, 04
Iguana mid-depth	IG-M	12° 30’ 3.6” - 81° 44’ 19.2.0”	11-12	Mixed corals and gorgonaceans	5	98, 99, 00, 01, 02, 03, 04
Iguana deep	IG-D	12° 30’ 5.2” - 81° 44’ 3.0”	16-18	Mixed corals and gorgonaceans	5	98, 99, 00, 01, 02, 03
Tayrona Natural Park						
Chengue shallow 1	CH-S-1	11° 19’ 32.2” - 74° 7’ 42.1”	3-5	*Montastraea* spp.	5	98, 99, 00, 01, 02, 03, 04
Chengue mid-depth 1	CH-M-1	11° 19’ 32.2” - 74° 7’ 42.1”	9-10	Mixed corals	5	98, 99, 00, 01, 02, 03, 04
Chengue deep 1	CH-D-1	11° 19’ 32.2” - 74° 7’ 42.1”	15-16	Mixed corals	5	98, 99, 00, 01, 02, 03
Chengue shallow 2	CH-S-2	11° 19’ 47.5” - 74° 7’ 43”	3-6	*Montastraea* spp.	5	98, 99, 00, 01, 02, 03, 04
Chengue mid-depth 2	CH-M-2	11° 19’ 47.5” - 74° 7’ 43”	9-11	Mixed corals	5	98, 99, 00, 01, 02, 03, 04
Chengue deep 2	CH-D-2	11° 19’ 47.5” - 74° 7’ 43”	15-17	Mixed corals and gorgonaceans	5	98, 99, 00, 01, 02, 03
Santa Marta Bay						
Punta Betín mid-depth	PB-M	11° 14’ 59.6” - 74° 13’ 15.2.0”	8-11	Encrusting corals on rock	5	98, 99, 03, 04
El Morro mid-depth	MO-M	11° 14’ 56.5” - 74° 13’ 54.7”	10-13	Encrusting corals on rock	5	98, 99, 03, 04
Rosario Islands						
Pavitos shallow	PA-S	10° 10’ 29.5” - 75° 46’ 14.3”	5-6	*Agaricia* spp.	5	98, 99, 01, 02, 03, 04
Pavitos mid-depth	PA-M	10° 10’ 29.5” - 75° 46’ 14.3”	9-12	*Agaricia* spp.-Mixed corals	5	98, 99, 01, 02, 03, 04
Pavitos deep	PA-D	10° 10’ 29.5” - 75° 46’ 14.3”	16-18	*Agaricia* spp.-Mixed corals	5	98, 99, 01, 02, 03
Tesoro shallow	TE-S	10° 14’ 3.1” - 75° 44’ 47.2”	5-6	*Montastraea* spp.	5	98, 99, 01, 02, 03, 04
Tesoro mid-depth	TE-M	10° 14’ 3.1” - 75° 44’ 47.2”	9-12	*Montastraea* spp.	5	98, 99, 01, 02, 03, 04
Tesoro deep	TE-D	10° 14’ 3.1” - 75° 44’ 47.2”	16-19	*Montastraea* spp.	5	98, 99, 01, 02, 03
San Bernardo Islands						
Mangle shallow	MA-S	9° 46’ 38.7” - 75° 47’ 7.4”	5-6	*Montastraea* spp.	3	02, 03, 04
Mangle mid-depth	MA-M	9° 46’ 46” - 75° 47’ 8.0”	9-12	*Montastraea* spp.	3	00, 02, 03, 04
Ceycen shallow	CE-S	9° 42’ 19.9” - 75° 51’ 58.1”	4-5	*Montastraea* spp.	3	02, 03, 04
Ceycen mid-depth	CE-M	9° 42’ 21” - 75° 51’ 57”	9-10	Mixed corals	3	00, 02, 03, 04
Minalta shallow	MI-S	9° 47’ 26.1” - 75° 55’ 24.2”	6-7	*Montastraea* spp.	3	02, 03, 04
Tiosolda mid-depth	TI-M	9° 49’ 19” - 75° 53’ 27”	9-10	Mixed corals	3	00, 02, 03, 04
Urabá Area						
Capurganá shallow	CA-S	8° 38’ 20.4” - 77° 20’ 40.8”	1-2	*Siderastrea siderea*	3	02, 03, 04
Capurganá mid-depth	CA-M	8° 38’ 31.4” - 77° 20’ 10.5”	11-12	Mixed corals	3	02, 03, 04
Cabo Tiburón shallow	CB-S	8° 40’ 13.5” - 77° 21’ 31.2”	2-3	*Siderastrea siderea*	3	02, 03, 04
Cabo Tiburón mid-depth	CB-M	8° 40’ 19.8” - 77° 21’ 24”	10-13	Mixed corals	3	02, 03, 04
Sapzurro mid-depth	ZA-M	8° 39’ 43.7” - 77° 21’ 31.4”	9-11	Mixed corals	3	02, 03, 04
Aguacate shallow	AG-S	8° 37’ 0.2” - 77° 19’ 36.7”	1-2	*Siderastrea siderea*	3	02, 03, 04
			PACIFIC			
Gorgona Island						
Azufrada shallow 1	AZ-S-1	2° 57’ 30.6” - 78° 10’ 41”	2 ¤	*Pocillopora* spp.	5	98, 99, 01, 02, 03, 04
Azufrada mid-depth 1	AZ-M-1	2° 57’ 30.6” - 78° 10’ 41”	4 ◆	*Pocillopora* spp.-*Pavona* spp.	5	98, 99, 01, 02, 03, 04
Azufrada shallow 2	AZ-S-2	2° 57’ 22.5” - 78° 10’ 50.1”	3 ◆	*Pocillopora* spp.	5	98, 99, 01, 02, 03, 04
Azufrada mid-depth 2	AZ-M-2	2° 57’ 22.5” - 78° 10’ 50.1”	5 ◆	*Pocillopora* spp.	5	98, 99, 01, 02, 03, 04
Playa Blanca shallow	PBL-S	2° 56’ 25.5” - 78° 11’ 35.1”	3 ❍	*Pocillopora* spp.	3	02, 03, 04
Playa Blanca mid-depth	PBL-M	2° 56’ 26.7” - 78° 11’ 26.1”	5 ❍	*Pocillopora* spp.-*Pavona* spp.	3	02, 03, 04

¤ At low tide; ◆ At high tide; ❍ At medium tide.

sites (CH-S-1) is located adjacent to the rocky shore and has a very complex coral community, which is composed principally by large boulders of *Montastraea faveolata* and skeletal remains of *Acropora palmata* (very few live colonies). The other shallow site (CH-S-2) is very similar but has more living branches of *A. palmata*, large colonies of *Siderastrea siderea* and a higher coral cover. The mid-depth sites are composed by medium-sized colonies of diverse coral species on gently reef slopes. Coral communities on the deep reef sites are located near the lower end of the reef slopes and are dominated by encrusting colonies of *Montastraea cavernosa* and *Diploria strigosa*. New monitoring reef sites have been added by SIMAC in TAY since 2003, but descriptions from these new sites are not presented in this paper.

Santa Marta (SMA): Is another small bay in the Santa Marta area (see general description of this area in previous paragraph about TAY). SMA is located adjacent to the port city of Santa Marta that has about 400 000 inhabitants. For that reason, a strong degradation of coral communities observed in the bay during last decades has been related principally with pollution both from the port and the city sewage (Werding & Sánchez 1988). Descriptions of coral formations of SMA are available since the early 1970´s (Antonius 1972, Erhardt & Werding 1975, Zea 1993). Two reef sites have been monitored by SIMAC in SMA since 1998, both at the mid-depth level. One is located in front of the rocky cape of Punta Betín (PB-M) where coral cover has declined to about 5% and the dominant coral species are now *M. cavernosa, D. strigosa* and *S. siderea*. The other reef site is adjacent to the SW end of El Morro, a rocky islet that closes the bay area to the North and support healthier coral communities dominated by *Meandrina meandrites, D. strigosa* and *M. cavernosa*.

Rosario Islands (IRO): Comprise a series of small coralline islands located in the central part of the continental Colombian Caribbean. Including all associated submarine environments, the complex takes up an area of nearly 120km^2 in which coral patches, fringing reefs, barrier reefs, shallow carbonate sand plains, seagrass meadows and mangroves create an intricate mosaic (Garzón-Ferreira & Díaz 2003). The reefs at these islands show the greatest development in the Northern coast of Colombia and are included within the natural park “Parque Nacional Natural Corales del Rosario y de San Bernardo” (Prahl & Erhardt 1985, Díaz *et al.* 2000, Cendales *et al.* 2002). Nevertheless, the islands are populated and tourism is very intense in the area. Furthermore, the influence of continental runoff on IRO has largely increased during recent times due to human alteration of nearby riverbeds (Garzón-Ferreira & Kielman. 1994). In consequence, many coral reefs around the islands are considerably damaged. Six reef sites for SIMAC monitoring stations were established since 1998 in the leeward coasts of Tesoro and Pavitos islands, where coral communities are in good shape. The shallow site is located near the outer margin of the fore-reef terrace where large coral patches composed by huge coral colonies (*Montastraea annularis, M. faveolata, Diploria labyrinthiformis* and *Colpophyllia natans*) alternate with sand shoals. Mid-depth and deep sites in Tesoro are situated on a reef slope, in front of the shallow site, and are covered by large colonies of a diverse coral assemblage but dominated by *M. annularis, M. franksi* and *C. natans*. In Pavitos, the shallow site is located also near the outer margin of the fore reef terrace, while the mid-depth and deep sites are located on a very steep reef slope. Dominant corals at the three sites in Pavitos are foliaceous species of *Agaricia*, principally *A. tenuifolia*, with some massive colonies of *M. annularis, M. faveolata* and *M. franksi*; many species of sponges are very abundant as well.

San Bernardo Islands (ISB): Consist of eight small to medium-sized islands and a series of shallow shoals that form an extensive mosaic of coral carpets, sand plains and seagrass meadows (Garzón-Ferreira & Díaz

2003). The origin, gross morphology and most characteristics of the coral associations are very similar to those from Rosario islands. In contrast to the Rosario islands, only a few studies have been carried out on the marine environment of ISB (Erhardt & Meinel 1975, Ramírez *et al.* 1994). A comprehensive study including thematic maps and characterization of the reef structures was carried out recently by López-Victoria & Díaz (2000). This work reported that the complex at ISB comprises an area of more than 250km^2, of which more than 60% corresponds to bottoms with notable coral cover (>60%) extending to depths of nearly 30m. Most of these coralline bottoms are included within the natural park "Parque Nacional Natural Corales del Rosario y de San Bernardo". Six monitoring reef sites were established by SIMAC at ISB in 2000-2002, three at the shallow level and three at the mid-depth level. The reef at the shallow site in Mangle (MA-S) has an imperceptible slope and is composed principally by large mounds of *M. annularis* and *M. faveloata* intermingled with sand shoals, while the mid-depth site there (MA-M) is more compact, located near a reef slope and dominated by *M. franksi*, *P. astreoides* and *A. tenuifolia*. The shallow site at Ceycen (CE-S) is situated on the top of an elongated patch reef where the coral community is diverse and includes numerous living colonies of *Acropora cervicornis*, whereas the mid-depth site there (CE-M) is near a reef slope and shows a high sedimentation and small colonies of numerous coral species. The shallow site at Minalta is on a large reef terrace with imperceptible slope and elongated coral formations alternating with sand channels, supporting numerous gorgonaceans, abundant algae and small to large coral colonies of *Montastraea* spp., *Diploria* spp., *S. siderea, C. natans* and *P. astreoides*. The mid-depth site at Tiosolda is located on a moderate reef slope with mixed coral species, including *M. cavernosa, M. franksi, Porites porites, P. astreoides* and *S. siderea*, as well as abundant octocorals and algae.

Urabá area (URA): Is in the Northwestern coast of the Urabá Gulf, near the Colombia-Panamá border, where the foothills of Serranía del Darien form steep rocky shores that plunge to depths of 15-30m. The waters of the gulf are highly influenced by terrestrial runoff due principally to large amounts of sediment and freshwater discharged by the Atrato River into the Southern part of the gulf. Very little information on the coral communities of URA was available until 1995, when a Colombian scientific expedition worked there intensively for six days to assess the distribution, extent, geomorphology, composition and health of coral formations (Díaz *et al.* 2000a, b, Garzón-Ferreira & Díaz 2003). Coral communities grow on the coastal hard substrate, developing fringing reef frameworks in sheltered coves. Six types of coral assemblages and 33 species of hard corals are known in URA. Six monitoring reef sites were established by SIMAC in 2002, three at the shallow level and three at the mid-depth level. All the shallow reef sites are fringing communities located near shore and dominated by large colonies of the coral *S. siderea*, which usually grow very close to each other covering a large portion of the substrate. Mid-depth sites are all located on the upper part of reef slopes and covered by a mixed community of coral species, including small flat to large colonies of *D. strigosa, D. labyrinthiformis, M. cavernosa* and *C. natans* and also abundant gorgonaceans.

Pacific

Gorgona Island (GOR): Is a well preserved natural park which sustains the largest, most mature and best studied coral reefs of the Colombian Pacific (Glynn *et al.* 1982, Prahl 1986, Zapata 2001, Zapata *et al.* 2001, Zapata & Vargas-Angel 2003). Although the island is located 30km from the coast, it is affected by continental run-off. Except for one small reef, all coral formations at GOR are located on the Eastern, leeward side of the island. Four plots were established in 1998 on La Azufrada fringing reef, the largest coral formation of GOR. This reef has at least 10 species of hard corals and is composed basically by *Pocillopora* spp. but also includes species of *Psammocora, Pavona, Porites* and *Gardineroseris*. Two other SIMAC plots were established in 2002 at Playa Blanca reef, which has a coral assemblage similar to that of La Azufrada with pocilloporids dominating the shallow areas and massive corals (particularly *Pavona* and *Gardineroseris*) forming some clusters on the outer reef base.

Protocol and methods

In order to design the SIMAC, a 3-day workshop was held in October 1998 (Garzón-Ferreira 1999). The workshop was attended by 28 professionals with at least some experience in reef issues, including research, management and education. Most of the time was expended selecting the relevant parameters to be included in a basic protocol, and the methodologies to measure them. At the end of the workshop, a proposal was agreed which was very similar to the CARICOMP protocols (CARICOMP 2001) for the coral reef communities. Basically, it consists of water quality measurements (temperature, salinity, turbidity) and a yearly estimation of benthic reef cover, coral disease incidence, gorgonian density, abundance of important mobile invertebrates, fish diversity and abundance of important fish species (Garzón-Ferreira 1999). These methods were reviewed during a second workshop held in November 1999 by 18 participants who examined the experience of the first year of monitoring and agreed on some minor changes to adjust the SIMAC protocols. Subsequently, a methods manual for SIMAC that describes the details of the sampling protocols was prepared (Garzón-Ferreira *et al.* 2002b) and published through the web page of INVEMAR (www.invemar.org.co).

The water quality protocol: Includes at least weekly measurements of surface temperature (bucket thermometer) and salinity (refractometer), and transparency of the water column (Secchi disk), as well as continuous bottom temperature recording (data logger). In the Santa Marta area, which is near our laboratory facility, we have been obtaining more information, including also weekly measurements of chlorophyll, suspended solids and nutrients in surface waters, as well as sedimentation rates at the reef bottom.

The cover of the reef surface: The cover by benthic organisms and non-living bottom categories is being estimated by the chain method in at least eighteen (18) fixed transects per reef area, distributed equally at two depth levels (3-6 and 9-12 m) and six reef sites (plots). The three transects at each depth level and site are chosen haphazardly within an homogeneous area of no more than 50 by 50m, but largely depending on the availability of appropriate substrata to fix the stakes that mark the ends of the transects. In some areas that were assessed first (San Andrés, Chengue and Rosario), there are 30 permanent transects distributed equally at three depth levels (3-6, 9-12 and 16-19m) and six reef sites (plots). The continuous line intersept transect method (Loya 1978), with a chain of 15.0-17.1mm link length, was used to estimate the percentage of the substrate covered by different benthic components. All components were grouped in primary (hard corals, algae, other sessile organisms, or abiotic substrate) and secondary categories (branching, massive or encrusting coral; turf, fleshy, or encrusting algae; sponges and other non-coral sessile organisms; rubble, rock or dead coral) following categories used by CARICOMP (2001). Only corals were identified to species level although difficulties in species identification were apparent mostly among the genus *Pocillopora* in Pacific sites and *Agaricia* and *Mycetophyllia* in Caribbean sites, due to high intraspecific variability and phenotypic plasticity. The percentage of the different substrate categories covering each transect was estimated as the number of chain links in contact or above a given substrate type relative to the total number of links in a transect. Each transect was considered a sampling unit and was 10m long following standard methodology in coral community studies (Loya 1978, CARICOMP 2001, 2003). The chain transect technique provides a precise measure of substrate cover and its topography, is efficient for estimating the relative abundance of species in the community and facilitates making comparisons with other studies (Ohlhorst *et al.* 1988; CARICOMP 2001). To ensure that the chain was laid down as exactly as possible along the same path year after year, a string was tightly tied between stakes at the ends of a transect and nails were driven on dead portions of some massive coral heads when present. The chain was then laid down under the string and in contact with the nails.

Estimates of coral disease prevalence: These are being done using the same fixed transects as a reference, examining every hard coral colony (>5cm) within a 2m wide band along each 10m transect. A PVC 1m pipe marked every 5cm is used as a reference to estimate colony size and band width while swimming at each side of the transect line. A colony is defined as the genetically distinct tissues (genet), which sometimes consist of separate but adjacent tissue sections (as is frequently the case with *M. annularis*) that could be identified as part of the same growth unit by similarities in skeletal morphology and tissue color. Each colony is identified to species level and its surface examined carefully to record the presence of any disease. In the case of coral communities dominated by dense branching stands where coral colony limits are not distinguishable, as in most Pacific sites, disease incidence along each band is surveyed by using a 1meter quadrant subdivided into 16 25 by 25cm squares with nylon line. The quadrant is laid consecutively along each side of the transect line, and at every quadrant position the corals contained within four of the 16 sub-quadrants (randomly chosen) are examined for coral diseases. Therefore, incidence in this case can be expressed as the proportion of sub-quadrants with diseased coral. Six basic types of coral diseases (Black Band, White Band, Yellow Band, Red Band, White Plague and Dark Spots) and bleaching are recorded in Caribbean sites, based on definitions provided by Santavy & Peters (1997), Goreau *et al.* (1998) and Garzón-Ferreira *et al.* (2001). Records of coral diseases for the Tropical Eastern Pacific are very scarce, so there is no review publication with definitions for this region.

The abundance of important mobile invertebrates: Invertebrates like lobsters, conch, octopuses, crabs and urchins, is being estimated through the examination of the same 10x2m belt transects on the sides of the fixed chain transects. Nevertheless, the sampling is focused on the following species of sea urchins: *Diadema antillarum, Eucidaris tribuloides, Echinometra viridis, E. lucunter* and *Lytechinus* spp. in the Caribbean, and *Diadema mexicanum, Hesperocidaris asteriscus* and *Echinometra vanbrunti* in the Pacific. Using a 1meter PVC pipe as reference, the surface, holes and caves of the reef bottom are carefully examined while progressively swimming along both sides of the transect line, recording every specimen present in the belt.

Fish communities: These are being monitored following a protocol similar to that proposed within the AGGRA program (Kramer & Lang 2003), which includes two types of visual censuses: a rover diver census (RD) to estimate fish species richness and a belt transect census (BT) to estimate abundance of selected important species. Fish censuses are conducted at the same general habitats and depth intervals of the reef where the permanent chain transects are installed. As many as possible BT censuses are performed at each monitoring site and for each one a 30m transect line is deployed on the reef bottom while recording during 7-10min the abundance of the selected species within a belt visually estimated to be 2m wide with the aid of a 1m PVC pipe. Juvenile parrotfishes and grunts (<5cm in total length) are not counted. Families selected for the BT censuses are those important for fisheries or significant for the ecology of the coral reef (Table 2). The RD census is conducted by swimming around for 30min, searching under overhangs, in caves, within sponges and so on to find as many fish species as possible, and estimating the abundance of each species by using logarithmic categories (A=1fish; B=2-10fishes; C=11-100fishes; D>100fishes). Each census is subdivided in two periods of 15min, the first one is done by swimming away from the center of the monitoring site through its deepest margin, and the second one by returning through the shallow level. At least two RD censuses are performed in two different sectors of the reef monitoring site.

TABLE 2
List of fish families selected for the belt transect censuses in SIMAC monitoring

Scientific name	Common name
Acanthuridae	Surgeonfishes
Balistidae	Leatherjackets
Carangidae	Jacks
Chaetodontidae	Butterflyfishes
Haemulidae	Grunts
Labridae	Wrasses
Lutjanidae	Snappers
Pomacanthidae	Angelfishes
Pomacentridae	Damselfishes
Scaridae	Parrotfishes
Serranidae	Groupers
Sphyraenidae	Barracudas
Tetraodontidae	Puffers

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RESUMEN

En respuesta al proceso de deterioro de los arrecifes coralinos colombianos en las últimas tres décadas, y con el propósito de establecer un sistema de vigilancia para el manejo apropiado de estos valiosos ecosistemas, el Instituto de Investigaciones Marinas y Costeras (INVEMAR) desde 1998 ha impulsando y puesto en marcha el Sistema Nacional de Monitoreo de Arrecies Coralinos en Colombia (SIMAC), con el apoyo de varias instituciones colombianas. El SIMAC ha operado sin interrupción por más de ocho años, periodo durante el cual se han establecido 63 parcelas permanentes de observación y 267 transectos fijos de evaluación, en diez de las principales áreas geográficas con arrecifes de Colombia (siete en le Caribe y tres en el Pacífico). Los procedimientos metodológicos del SIMAC se hallan descritos detalladamente en el manual de métodos e incluyen: cobertura del bentos arrecifal, densidad de gorgonáceos, prevalencia de enfermedades coralinas, abundancia de invertebrados móviles selectos, riqueza ictiológica y densidad de familias selectas de peces, así como algunas variables indicadoras de la calidad del agua. Los resultados del SIMAC han sido circulados a través de reportes resumen para las agencias del gobierno y público en general y han apoyado iniciativas regionales y globales de monitoreo (i.e. CARICOMP, GCRMN, ReefBase). En este artículo se describe el desarrollo de este sistema y en otros artículos dentro de este número especial se presentan los principales resultados del monitoreo.

Palabras clave: arrecifes coralinos, monitoreo, SIMAC, GCRMN, Colombia.

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