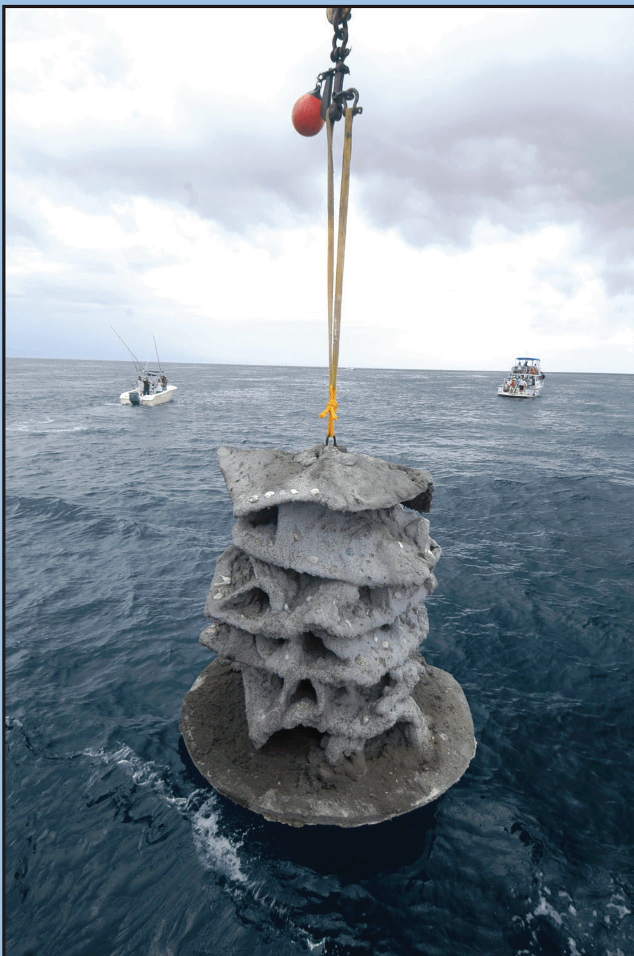
Marine Artificial Reef Research and Development

Integrating Fisheries Management Objectives



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An Integrative Artificial Reef Project for Conservation and Coastal Management in the Colombian Caribbean

Oscar Delgadillo-G*
MoAm S. A. S.
Calle 87 #2-53 Of, 101 Bocasalinas, Pozos Colorados, Santa Marta 470006, Colombia

Nirith N. Toro
Ecopetrol S. A.
Terminal Pozos Colorados, Santa Marta 470006, Colombia

Abstract.—Multiple coastal development activities coupled with unsustainable management have caused environmental degradation in the Santa Marta region of Colombia. To mitigate this impact, Ecopetrol entered into alliances with private and government institutions to initiate an integrative artificial reef project in Pozos Colorados Bay. To develop the project's framework, it was necessary to (1) establish context and objectives, (2) design plans and reef construction, (3) strengthen a target social population, and (4) conduct pre- and postdeployment ecological assessments. The achievement of each objective was met with delays and constraints, mainly due to administrative issues and legal requirements. Nevertheless, interventions and interactions among representatives of the 10 institutions involved in the project, as well as the strong commitment of fishers from three organizations in all stages of the process, were indicators of project's success. Together, these actions and contributions resulted in the deployment of the first six artificial reefs in a 137-ha area. Moreover, recorded changes in biological assemblages before and after reef deployment (richness: 3–37 species; abundance: 30.3–1,615.7 individuals), along with the presence of commercial, ecological, and endangered important species, support the concept of habitat enhancement procedures used here as a strategy for biodiversity conservation with potential for ecotourism activities. The utilization of this technology should be conducted in compliance with concerted schemes for coastal resource management and precautionary principles, directed towards the conformation of discrete marine reserves as future models of sustainable production in sensitive areas.

* Corresponding author: odelgadillo@moam.com.co

Introduction

Artificial reef technology around the globe has generally focused on the enhancement of artisanal and industrial fishery production as its main goal (Seaman and Jensen 2000; Bortone 2011). In recent decades, its objectives and applications have expanded to include ecological restoration, mitigation, mariculture, research, and biodiversity conservation (Lindberg and Relini 2000; Seaman 2002, 2007). Trends in world fisheries production have shown evidence of substantial fish stock depletion and species decline, especially in developing countries where appropriate management is lacking and data from small-scale fisheries have often been ignored (Costello et al. 2012; Pauly and Zeller 2016). Consequently, an alternative for the application of artificial reefs in a socioecological context, similar to that in Japan and France, discussed by Pioch et al. (2011), should be conducted. This approach should involve integrative management strategies to encourage local, vulnerable fishing communities to protect, restore, and make sustainable use of the marine natural resources.

Santa Marta, in the Caribbean Sea of Colombia, is an area of high diversity, both geographically and environmentally. As part of the largest coastal mountain system in the world, the Sierra Nevada of Santa Marta influences local weather and imparts structure to the coastline and continental shelf. These features, among others, provide a high variety to the coastal ecosystems and habitats, which include extensive protected areas and sanctuaries consisting of coral reefs, sea grass beds, and mangrove forests biotopes. Contributing to the heterogeneity of the environment, an upwelling event during the first months of each year, coupled with complex oceanographic and hydrological systems, increases the general productivity and fishery potential in this coastal region (Díaz et al. 2000, 2003; Idárraga-García et al. 2011; García et al. 2013).

The area has also experienced significant coastal development, including port facilities for hydrocarbons and coal transportation and an expansion of ecotourism. Pollution, owing to local development along with the unsustainable administration of natural resources and the effects of climate change, has led to environmental degradation, a reduction in fishery productivity, and the loss of traditional fishing grounds. All these factors have negatively affected fishing and fishing communities (Díaz et al. 2000, 2003; García et al. 2007; García 2010). Under these environmental and social conditions, Ecopetrol (i.e., the leading company on oil and gas business in Colombia, formerly known as the Colombian Petroleum Company), within its corporate social responsibility policy, locally contributes to the sustainable utilization of natural resources. Ecopetrol helped form alliances with a variety of stakeholders and cooperators to promote the governance of a plan to deploy artificial reefs. The goals of the strategy were met by strengthening the technical and organizational capacity of fishermen in the associated communities. Aiming to assess the feasibility and potential benefits of this integrative approach for management in the socioecological context, this plan emphasizes pathways for its implementation and preliminary results during the first stage.

Methods

Planning Context and Objectives

The first step in the process of achieving the plan's objectives was to determine the environmental, management, and socioeconomical characteristics of the potential site or location for artificial reef deployment. The second step was to identify particular problems in the target social population and to suggest remedies to resolve the problems. The third step was to establish potential interinstitutional agreements needed for participation, planning, and investment. Last, after the completion of the previous requirements, the management and research objectives of the project were defined (Lindberg and Relini 2000; Pioch et al. 2011).

Artificial Reef Building and Deployment Plans

To facilitate planning the materials, design, and sites for artificial reef deployment, the basic environmental characteristics of the area (i.e., physical, chemical, and biological) were evaluated through the review of already available information and field surveys. As is true for projects in any country when contemplating an intervention of this magnitude, licenses and permissions for artificial reef transport, deployment, research, and environmental viability were managed with different government institutions and stakeholders, including the establishment of industrial security protocols for these processes (Bortone et al. 2000; Sheng 2000; Wilding and Sayer 2002).

Strengthening of Target Fishing Communities

The various features, needs, and requirements of the target social group with regard to the fishery, education, and technical organization were identified to more easily achieve coastal stewardship and project appropriations. Accordingly, a variety of supporting activities, training, and technological transference were conducted.

Pre- and Postecological Assessments of Fishes and Mobile Macroinvertebrates

Besides conducting a review of already existing information, pre- and initial postdeployment assessments of fishes and mobile macroinvertebrates associated with the artificial reefs were performed using a random visual census (Bortone et al. 2000; Delgadillo-Garzón et al. 2004). These visual censuses consisted of two divers estimating faunal composition, species abundance, and size using scuba during five regular time intervals of 6 min each per station for a total of 30 min per diver. Species richness and relative abundance were calculated from the average of the 10 time intervals for each census day and station and were expressed as a count per unit of effort. The comparisons between pre- and postdeployment census were performed with a nonparametric Mann–Whitney U-test (Zar 2010).

Results

Environmental and Socioeconomical Context

Pozos Colorados Bay is located on the east side of the Gulf of Salamanca, between Punta Gloria and Punta La Loma, in the southwest sector of the city of Santa Marta (11°06'00"–11°09'00" N and 74°14'00"–74°16'00" W) in the Magdalena Department, Caribbean of Colombia (Figure 1). Pozos Colorados Bay has a continuous coastline length of 6.7 km, with depths between 0 and 30 m on the typically narrow continental shelf and a maximum width of 16 km. The area also receives the direct and indirect influence of Magdalena River and Ciénaga Grande of Santa Marta (coastal lagoon), with heavy runoff from these and other nearby continental sources. The bay has a limited amount of hard substrate (rock conglomerate) and sea grass beds, although there are some sites with rocky littoral zones. The bottom is predominantly mud (73%) and very fine sand (27%) with no readily apparent association of substrate type with depth.

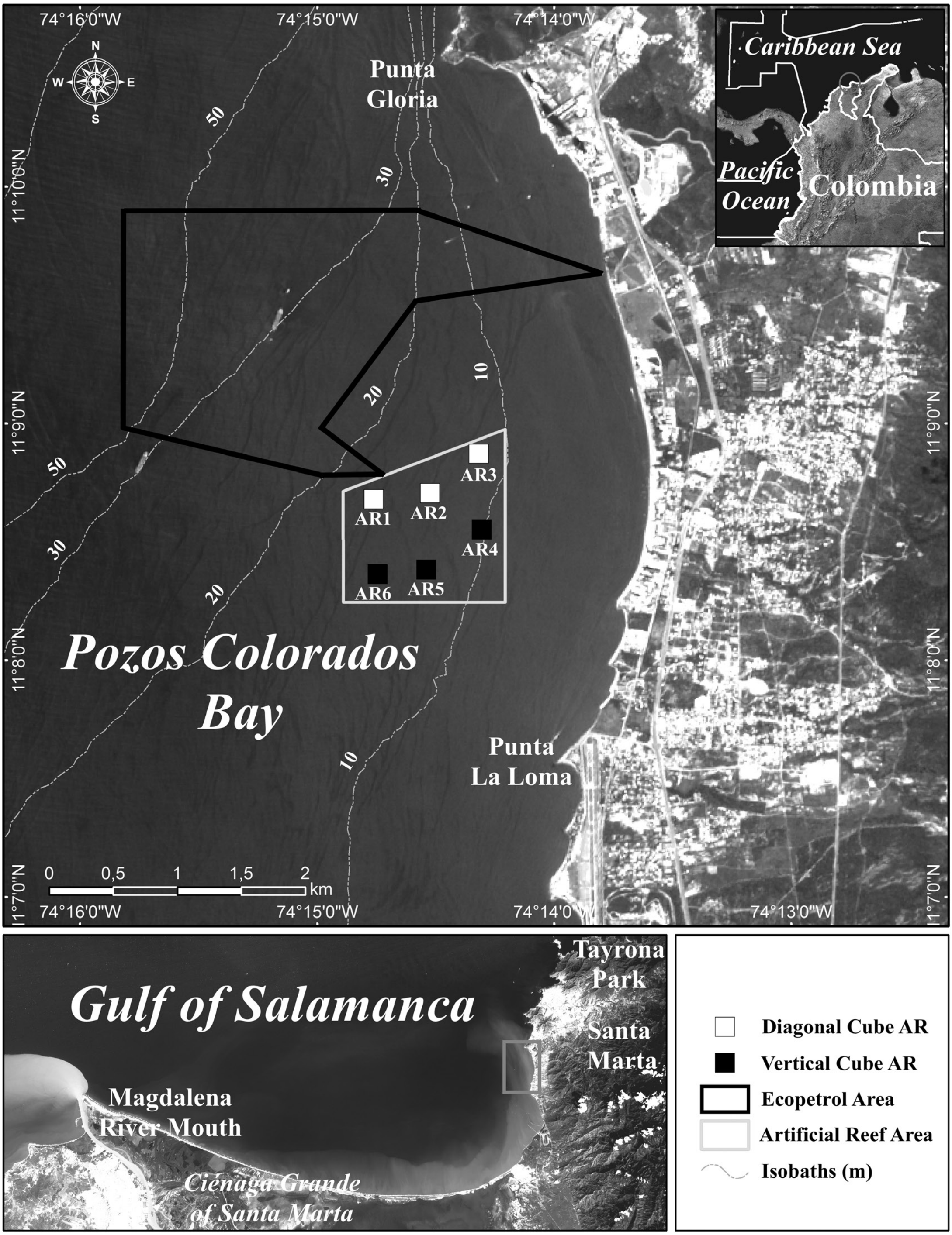

Figure 1. Location of Pozos Colorados Bay in the Gulf of Salamanca indicating the position of the artificial reefs.

The dry season extends from December to April with strong influence of Alisios winds from the north-northeast, which causes upwelling during these months. The wet season extends from April to November with winds from the south-southwest. Water temperature ranges from 21°C to 30°C and salinity from 27‰ to 38‰ (Guzmán-Alvis and Díaz 1996; Ramírez-Calle and Valencia-Vera 2005; García et al. 2013; Delgadillo-G and Flórez 2015).

Fishery resources within the continental shelf limits in the Gulf of Salamanca are highly diverse and productive, with at least 280 fish species of commercial and ecological importance (García and Armenteras 2015). Additionally, the artisanal fishing community is composed of no less than 1,800 fishers, excluding those fishers whose fishing activity is restricted to coastal lagoons and freshwater systems. The fishers use a wide variety of gears, such as hook and line, longline, gill nets, beach seines, shrimp beach seines, casting net, pots, speargun, and changa (small, modified artisanal trawls), conducting their fishing mainly from wood canoes with oak and sail or fiberglass boats with small, outboard engines (Rueda et al. 2010).

The environmental features of the region have facilitated port development, including the creation of restricted areas for industrial activities (e.g., pipes and monobuoys for oil transport, anchoring zones for vessels and coal transference, and industrial navigational routes). Additionally, in past years, Pozos Colorados Bay has experienced intense urban expansion along with an increase in the activities and infrastructure associated with tourism. In this context, the area of Ecopetrol marine operations within the bay (Figure 1) also includes the activities of artisanal fishing communities associated with several fishing organizations (e.g., Aspescoltur, Asopesmar, Copepazbe, Asocumar, Asopesbaga, Adimujer, and Asopozoscolorados). According to García (2010), these social groups are confronted with the effects of inshore and offshore industrial development, fishery overexploitation, pollution, climate change, and unsustainable management of natural resources. The effects of each of these is associated with a reduction in fishing productivity, the displacement of fishers from their traditional fishing grounds, environmental degradation, and a scarcity of government investment to mitigate these effects.

To initiate planning the artificial reef project, Ecopetrol entered into agreements and formed strategic alliances with 10 government and private stakeholders, including the University of Magdalena, Drummond Ltd., Foundation of Port Society of Santa Marta, INCODER (Colombian Institute of Rural Development), CORPAMAG (Regional Autonomous Corporation of Magdalena), AUNAP (National Authority of Aquaculture and Fishing), SENA (National Learning Service), Irotama Resort, Estelar Hotel, and MoAm, among others. Each agreement had partner-specific roles within the project. Consequently, one intended management objective was to strengthen the technical and organizational capacity of fishing communities while the research objectives for the artificial reefs were to determine their effectiveness in the conservation of biodiversity and their potential for promoting ecotourism.

Artificial Reef Design, Building, and Deployment

In accordance with the environmental characteristics of the study area and considering past successful performance with the first steel-pipe artificial reefs deployed in 2000 in the Gulf of Morrosquillo (Delgadillo et al. 2004; Delgadillo-Garzón and García 2009), refuse steel pipe (formerly used for oil transport) was used as a material of opportunity to create artificial reef modules. The design, configuration, and arrangement of the modules during the present project were designed to increase reef stability and complexity, which were identified as problematic for the recent (2007–2010) artificial reefs deployed in the Gulf of Morrosquillo (Delgadillo-Garzón et al. 2010).

Between May and October of 2011, 500 m of steel pipe (46 cm diameter, 1 cm thick) in 6-m-long sections were recycled to build the artificial reefs. Residual hydrocarbons (e.g., tar) were cleaned from each pipe by striking and scraping both internal and external surfaces. Subsequently, pipes were cut to length using oxyacetylene torch and high-pressure welding to assemble the pipes into a finished structure. Six artificial reefs designed by MoAm were built in a cubic-frame configuration of 4.5 × 4.5 × 4.5 m, three of them with crossing diagonal pipes between the main frame (diagonal cube model) and the other three with a row of eight vertical, 2-m pipes in the middle of the box (vertical cube model). To increase their complexity and for ecological research purposes, various pipes were drilled with holes of 5 and 20 cm diameter. The weight of the artificial reefs modules was between 9.9 and 11.2 metric tons (Table 1; Figure 2).

Licenses and permits were processed and obtained between 2011 and 2013 after the fulfillment of all the documentation required by different government entities (Table 2). A basic characterization of the bathymetric, oceanographic, and sediment features of the area determined that the minimum depth (i.e., clearance) of the artificial reefs (i.e., between the lowest water surface level and the highest part of the reef) did not represent any hazard to navigation. Additionally, the analysis of the prevailing currents and sediment dynamics relative to the arrangement and location of the structures did not indicate any appreciable negative effects on local oceanographic patterns and beach sediment deposition. Subsequent to these activities, the General Maritime Directorate of Colombia adopted Resolution No. 0018 in January 2013 with a maritime area of 137 ha for artificial reef development and requirements for their use. Regarding management, postplacement commitments for the utilization of the permitted area included posting signs on the polygon vortex, deploying buoys to mark the area for management, maintenance of the marking system, and the delivery of reports of the artificial reefs' performance.

After establishing security protocols for terrestrial and maritime transportation based on international procedures and local policy requirements, Drummond Ltd. conducted the deployment of the artificial reef modules using the tugboat *Michael T*, the crane vessel *Seaworthy*, and the participation of a maritime expert. The deployment operation at depths between 10 and 16 m in the permit area was successfully executed on the morning of June 7, 2013 (Figures 1 and 2; Table 1).

Strengthening Fishing Communities

The first stage of improving community organization was achieved by interacting with three target communities proximate to the area directly under the influence of Ecopetrol. The fishing associations Aspescoltur, Copepazbe, and Adimujer were comprised of a total of 75 fishermen. Different approaches were used to fulfill all their requirements and needs, as follows.

Education and Related Activities

SENA educated the community on business plans and cooperative management. As a re-

Table 1. Features of the artificial reefs deployed in Pozos Colorados Bay (*D*: depth; *V*: volume; TH: total of holes; DC: distance to the coast; DNA: distance to the nearest artificial reef; DRR: distance to the rocky reef; ø: number of holes of 46, 20, and 5 cm of diameter).

Artificial reef (AR)	Model	Coordinates datum WGS84	*D* (m)	*V* (m^3)	TH	DC (m)	DNA (m)	DRR (m)	ø46	ø20	ø5
AR1	Diagonal cube	11° 08' 40.9" N–74° 14' 45.6" W	15.9	91	153	2,130	254	1,840	8	20	125
AR2	Diagonal cube	11° 08' 42.4" N–74° 14' 31.4" W	14.1	91	153	1,700	280	1,430	8	20	125
AR3	Diagonal cube	11° 08' 52.4" N–74° 14' 19.1" W	12.9	91	153	1,320	486	1,260	8	20	125
AR4	Vertical cube	11° 08' 33.1" N–74° 14' 18.3" W	10.6	91	44	1,280	421	978	24	20	0
AR5	Vertical cube	11° 08' 23.0" N–74° 14' 32.3" W	12.1	91	44	1,630	326	1,350	24	20	0
AR6	Vertical cube	11° 08' 21.9" N–74° 14' 44.6" W	14.6	91	44	1,990	253	1,690	24	20	0

Figure 2. Artificial reefs during the deployment operation in Pozos Colorados Bay: **(a)** diagonal cube module, **(b)** vertical cube module.

sult, the associations were legally formed and certified as an organization by the Chamber of Commerce. This facilitated the community's ability to receive materials, make use of facilities, and benefit from opportunities provided by public and private institutions. The University of Magdalena instructed the community in the processing and manufacture of food, seeking to teach each community how to generate aggregate value in the fishery products for commercial purposes.

Environmental education activities (i.e., workshops) were conducted by the university within the community for a wide age range of individuals (between 8 and 60 years old). Workshops included topics and activities that addressed (1) the management of wild fauna and threatened species, (2) ecosystem conservation, (3) the identification of marine and coastal species, and (4) beach cleaning and residue management. Additionally, together, INCODER and AUNAP developed a workshop on status, laws, and responsible fishing practices regarding artisanal fishery activities in Colombia. Likewise, MoAm performed workshops regarding artificial reefs and habitats, environmental management, and biodiversity.

Training and Equipment Support

SENA instructed fishermen in the proper use of outboard engines, including mechanics, function, utilization, and repairing. The objective here was to increase the fishermen's capacity to overcome any problems associated with fishing activities at sea as well as to reduce operation costs. In cooperation with a local scuba business, two fishermen received training in open-water diving to promote active participation and technical support in the activities of monitoring and future diving ecotourism.

To support and reinforce artisanal fishery capacity, fishing organizations associated with the project received loans of two fiberglass boats 7.6 m (25 ft) long, two 40-hp and two 15-hp outboard engines, and fishing gear such as gill nets, ropes, nylon materials, and various-sized hooks. INCODER and AUNAP also supported this project by providing equipment to enhance safety and facilitate navigation, such as life vests, buoyancy aids, and radios for communication.

Pre- and Postdeployment Ecological Assessment

The preassessment visual census surveys conducted by scientific divers at the pro-

Table 2. Summary of the dependent group and requirement responsibility attributable to each regulatory institution for the development of an artificial reef project in Colombia.

Regulatory institution	Dependency	Requirements	Final result
1. Ministry of Commerce, Industry and Tourism	Group of Planning and Sustainable Development of Tourism	• Project profile • Flat and geographic coordinates of artificial reef positions and estimated area required for the project	Certified of existence or not of touristic projects in the area
2. Ministry of Transport	Group of Infrastructure for Port Development and Logistics	• Project profile • Drawing of the specific location with flat coordinates of artificial reef positions and area required for the project	Certified for the procedure of concession for public use area
3. Ministry of the Interior	Missional Area, Direction of Previous Consult	• Project profile • Project cartographic location in shape files (shp) and Magna Sirgas of artificial reef position and area of the project	Certified of presence or not of ethnic groups
4. Ministry of Environment and Sustainable Development	National Agency of Environmental Licenses	• Project profile • Environmental characterization (i.e., physical, chemical, biological, oceanographic, geological) • Socioeconomical description • Navigational, industrial and governance characterization • Artificial reef description and evaluation plan	Environmental license
5. Regional Autonomous Corporation of Magdalena (Corpamag)	Subdirection of Environmental Management	• Project profile • Environmental characterization (i.e., physical, chemical, biological, oceanographic, geological) • Artificial reef description and evaluation plan	Environmental feasibility and research permit
6. General Maritime Directorate (DIMAR)	Area of Littorals	• Project profile • Artificial reef description, deployment, and evaluation plan • Certified and licenses from the regulatory institutions • Flat and geographic coordinates of artificial reef positions and area required for the project • Publication of an edict with basic information of the artificial reef project	Resolution with the area in concession and committments for management

posed artificial reefs deployment sites indicated three predominant fish species with a total relative abundance of 30.3 individuals per survey. Higher richness was recorded on site AR5 with a total of three species and an average of two species per survey (SD ± 1) while site AR1 had a total relative abundance of 17.8 individuals and a mean of 5.9 individuals per census (SD ± 5.3). The most abundant species was Blue Runner *Caranx crysos* with a total of 28.5 individuals per survey (Table 3; Figure 3).

After the artificial reef deployment, initial surveys during the first 3 months indicated changes in the biological variables of the area, with a total of 28 fish species and 1,592.1 organisms. Higher biological parameters were recorded at site AR6 with 17 species and site AR3 with 371.7 individuals. The average richness and relative abundance per site were 8.5 (SD ± 1.61) and 132.6 (SD ±48.7), respectively. The abundant fishes in descending order were Atlantic Bumper *Chloroscombrus chrysurus* (1,299.4), Atlantic Spadefish *Chaetodipterus faber* (81.7), and Atlantic Thread Herring *Opisthonema oglinum* (61.1) (Table 3; Figure 3). Two endangered species were recorded, according with the *Red Book of Marine Fishes of Colombia* (Chasqui et al. 2017): the critically endangered Goliath Grouper *Epinephelus itajara* and the vulnerable Mutton Snapper *Lutjanus analis*. Additionally, the Lane Snapper *L. synagris* was in the category of least concern. The Mann–Whitney test to compare pre- and postdeployment surveys indicated significant differences in richness ($W = 0.5$; $p < 0.001$) and relative abundance ($W = 0$; $p < 0.001$) of fishes.

Regarding mobile macroinvertebrates, none was observed in the preassessment survey. During postdeployment assessment, nine species and 23.6 individuals were observed associated with the artificial reefs, with the highest parameters recorded on site AR6 (7 species richness and 9.5 individuals). The mean values per artificial reef were 1.75 species (SD ± 1.17) and 1.96 individuals (SD ± 1.62). Abundant species in descending order were redbanded coral shrimp *Stenopus hispidus* (18.9) and bareye hermit *Dardanus fucosus* (1.3) (Table 4; Figure 4). The Mann–Whitney test to compare pre- and postdeployment survey indicated significant differences in richness ($W = 27$; $p < 0.001$) and relative abundance ($W = 27$; $p < 0.001$) of macroinvertebrates.

Discussion

Pozos Colorados Bay is an ideal area for an artificial reef project owing to its environmental conditions and socioeconomic circumstance. For example, the bay is absent natural, structure-based ecosystems or natural hard substrate and this inhibits some species from becoming established in the bay. Also, there are fishing communities in the bay that constantly exploit the diversity of fishery resources in the general area alongside. Last, there are already established regulations in place to control human activity in the area relative to coastal development. Hence, this provides the perfect scenario to demonstrate the positive effects of an integrative approach for habitat enhancement as an alternative strategy for concerted environmental management.

The high level of interaction among stakeholders is evidence of the public interest in supporting policies for local inhabitants. This interaction was similar to that observed in other areas of Colombia, such as the Gulf of Morrosquillo (Delgadillo-Garzón et al. 2010), and in other countries, like Japan and France (Pioch et al. 2011). Often, stakeholders take part in environmental projects according to their ability to accomplish the expected results. As was pro-

Table 3. Composition and relative abundance of fishes recorded during the pre- and postdeployment assessment of the artificial reefs in Pozos Colorados Bay (* species on the Red List of Colombia; *n*: number of surveys in each artificial reef; AR = artificial reef).

	Predeployment assessment (n = 3)							Postdeployment assessment (n = 2)						
Species	AR1	AR2	AR3	AR4	AR5	AR6	Total	AR1	AR2	AR3	AR4	AR5	AR6	Total
Blue Tang *Acanthurus coeruleus*	–	–	–	–	–	–	–	0.6	0.5	–	–	0.1	–	1.2
Redspotted Hawkfish *Amblycirrhitus pinos*	–	–	–	–	–	–	–	–	0.1	–	–	–	0.2	0.3
Porkfish *Anisotremus virginicus*	–	–	–	–	–	–	–	1	–	0.3	–	0.4	0.6	2.3
Sharpnose Puffer *Canthigaster rostrata*	–	–	–	–	–	–	–	10.9	4	17	15.2	7	1.6	55.7
Blue Runner *Caranx crysos*	17.8	–	0.6	–	10.1	–	28.5	0.4	2.2	–	0.3	2.2	–	5.1
Horse-eye Jack *Caranx latus*	–	–	–	–	–	–	–	–	–	0.1	–	–	–	0.1
Atlantic Spadefish *Chaetodipterus faber*	–	–	–	–	–	–	–	12.8	13	29.5	8.8	10	7.6	81.7
Spotfin Butterflyfish *Chaetodon ocellatus*	–	–	–	–	–	–	–	–	–	0.5	0.5	–	–	1
Reef Butterflyfish *Chaetodon sedentarius*	–	–	–	–	–	–	–	–	–	0.6	–	–	–	0.6
Atlantic Bumper *Chloroscombrus chrysurus*	–	–	–	–	–	–	–	75	298.6	270.1	255	250.6	150.1	1299.4
Dwarf Sand Perch *Diplectrum bivittatum*	–	–	–	–	–	–	–	0.5	0.5	0.6	–	0.7	1.1	3.4
Atlantic Goliath Grouper *Epinephelus itajara**	–	–	–	–	–	–	–	–	–	0.2	–	–	–	0.2
Eucinostomus sp.	–	–	–	–	–	–	–	–	1.1	–	–	–	5.7	6.8
Goldspot Goby *Gnatholepis thompsoni*	–	–	–	–	–	–	–	–	–	–	–	–	0.1	0.1
Tomtate *Haemulon aurolineatum*	–	–	–	–	–	–	–	7.8	2.1	–	2.8	–	10.1	22.8
Latin Grunt *Haemulon steindachneri*	–	–	–	–	–	–	–	3.8	4.7	2	15.7	4.5	1.3	32

Table 3. Continued.

Species	Predeployment assessment (n = 3)							Postdeployment assessment (n = 2)						
	AR1	AR2	AR3	AR4	AR5	AR6	Total	AR1	AR2	AR3	AR4	AR5	AR6	Total
Mutton Snapper *Lutjanus analis**	–	–	–	–	–	–	–	–	0.1	–	–	–	–	0.1
Lane Snapper *Lutjanus synagris**	–	–	–	–	–	–	–	0.3	0.7	–	0.2	–	0.8	2
Leatherjack *Oligoplites saurus*	–	–	–	0.2	0.3	–	0.5	–	–	–	–	–	–	–
Atlantic Thread Herring *Opisthonema oglinum*	–	–	–	–	1.3	–	1.3	–	–	50	10	0.2	0.9	61.1
Paralichthys sp.	–	–	–	–	–	–	–	0.3	–	–	–	–	–	0.3
Postlarvae	–	–	–	–	–	–	–	0.6	–	–	–	0.7	–	1.3
Red Lionfish *Pterois volitans*	–	–	–	–	–	–	–	1.3	–	0.7	0.5	0.4	0.7	3.6
Cobia *Rachycentron canadum*	–	–	–	–	–	–	–	–	–	–	–	–	0.1	0.1
Twinspot Bass *Serranus flaviventris*	–	–	–	–	–	–	–	–	0.1	–	0.6	–	0.3	1
Pelican Barracuda *Sphyraena guachancho*	–	–	–	–	–	–	–	–	–	0.1	–	–	–	0.1
Bicolor Damselfish *Stegastes partitus*	–	–	–	–	–	–	–	–	–	–	–	–	0.4	0.4
Black Brotula S*tygnobrotula latebricola*	–	–	–	–	–	–	–	–	–	–	–	0.3	–	0.3
Bluehead *Thalassoma bifasciatum*	–	–	–	–	–	–	–	–	6.4	–	–	1.2	1.5	9.1
Total relative abundance	17.8	0	0.6	0.2	11.7	0	30.3	115.3	334.1	371.7	309.6	278.3	183.1	1592.1
Total richness	1	0	1	1	3	0	3	13	14	13	11	13	17	28

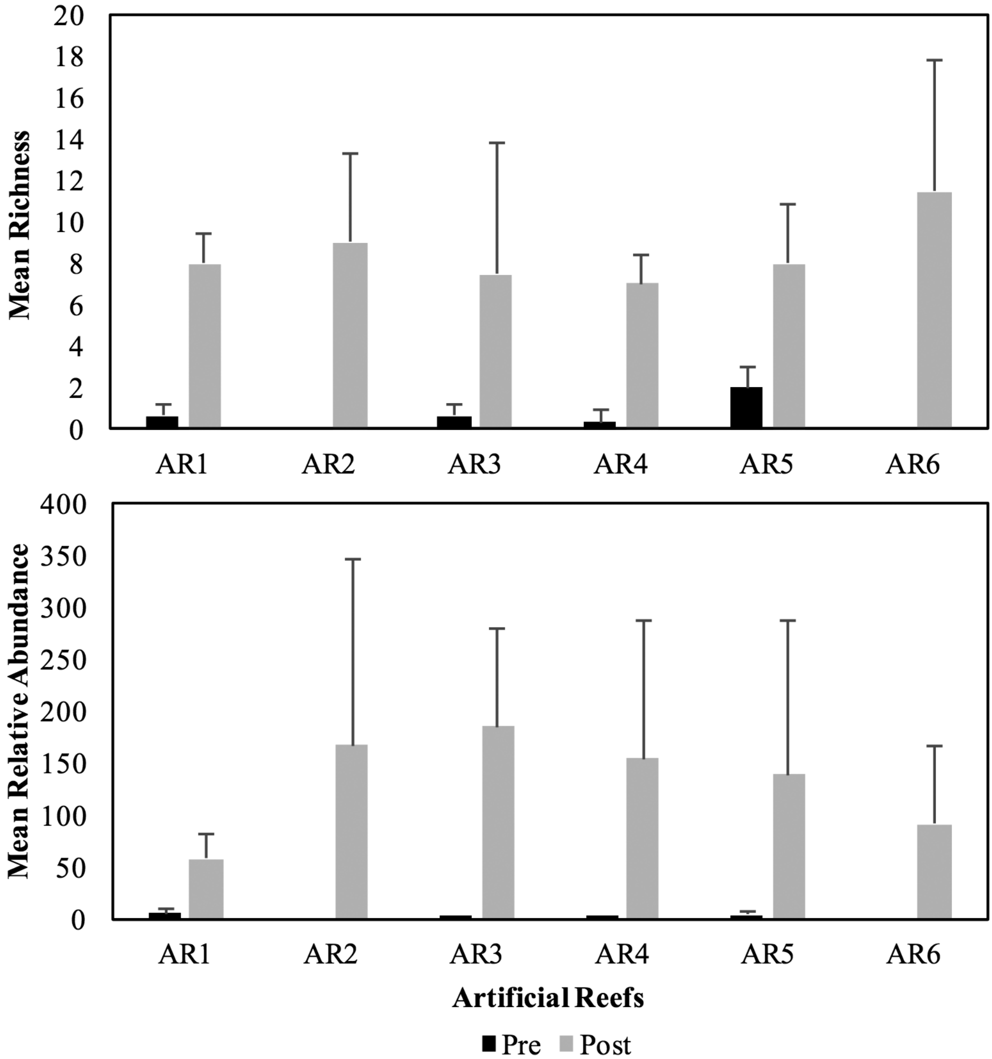

Figure 3. Mean richness and relative abundance of fishes recorded during pre- (Pre) and post- (Post) deployment assessments of the artificial reefs (AR) in Pozos Colorados Bay (bars represent standard deviation).

posed in the management objective here, the education, training, and economic support have facilitated the strong commitment of the target group to improve their technical-organizational capacity. This objective has been partially fulfilled due to the long-term intervention required to achieve most consistent results. The step-by-step integration between the institutions and stakeholders as well as the sense of ownership created by the involvement of fishers in the technical activities related with the processes were positive indicators of success.

Recycling steel pipe as a module of opportunity for building designed reefs is a promising procedure for the disposal and reutilization of waste material in an environmentally sound manner to enhance marine natural processes. The life span of steel in the seawater environment is up to 300 years,

Table 4. Composition and relative abundance of mobile macroinvertebrates recorded during pre- and postdeployment assessment of the artificial reefs in Pozos Colorados Bay (n: number of surveys in each artificial reef). AR = artificial reef.

	Predeployment assessment (n = 3)							Postdeployment assessment (n = 2)						
Species	AR1	AR2	AR3	AR4	AR5	AR6	Total	AR1	AR2	AR3	AR4	AR5	AR6	Total
Phylum Annelida														
Bearded fireworm *Hermodice carunculata*	–	–	–	–	–	–	–	–	–	–	–	0.1	0.3	0.4
Phylum Mollusca														
Western dondice *Dondice occidentalis*	–	–	–	–	–	–	–	–	–	–	–	–	0.4	0.4
Monoplex pilearis	–	–	–	–	–	–	–	–	–	0.1	–	–	0.2	0.3
Voluta virescens	–	–	–	–	–	–	–	–	0.4	–	0.4	–	–	0.8
Phylum Arthropoda														
Subphylum Crustacea														
Spiny hands *Charybdis hellerii*	–	–	–	–	–	–	–	–	–	–	0.5	–	–	0.5
Bareye hermit *Dardanus fucosus*	–	–	–	–	–	–	–	1.1	–	–	–	–	0.2	1.3
Mithrax sp.	–	–	–	–	–	–	–	–	–	–	–	–	0.2	0.2
Redbanded coral shrimp *Stenopus hispidus*	–	–	–	–	–	–	–	0.6	0.4	2	2.7	5.5	7.7	18.9
Yellowline arrow crab *Stenorhynchus seticornis*	–	–	–	–	–	–	–	–	–	–	–	0.3	0.5	0.8
Total relative abundance	–	–	–	–	–	–	–	1.7	0.8	2.1	3.6	5.9	9.5	23.6
Total richness	–	–	–	–	–	–	–	2	2	2	3	3	7	9

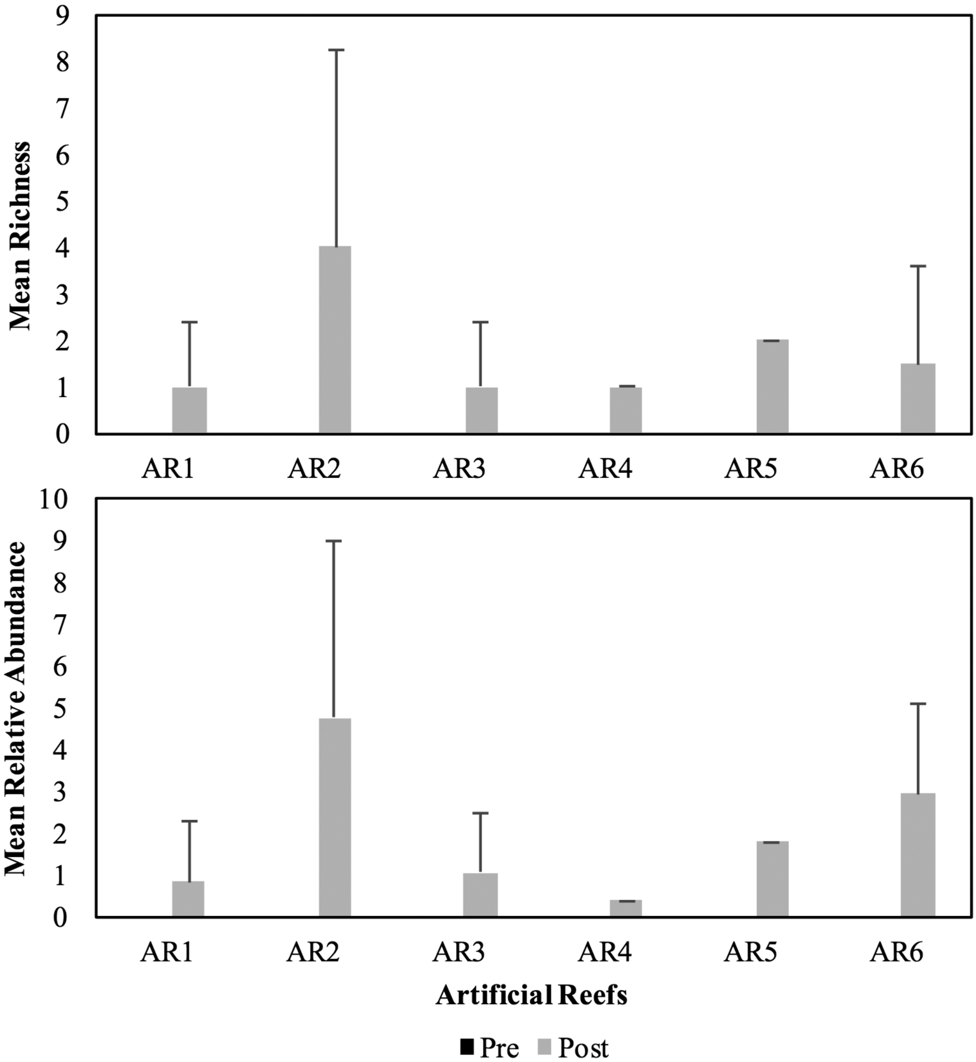

Figure 4. Mean richness and relative abundance of mobile macroinvertebrates recorded during pre- (Pre) and post- (Post) deployment assessment of the artificial reefs (AR) in Pozos Colorados Bay (bars represent standard deviation).

depending on the type and condition of the steel (Lukens and Selberg 2004). The availability of pipes with a variety of diameters from Ecopetrol offers the possibility to explore different applications of ecological design and engineering in restoration and mitigation, as stated by Grove et al. (1991) and Sheehy and Vik (1992). Pipe availability provides an opportunity to evaluate the implementation of specific designs to test ecological hypothesis and improve the requirements of target species (Lindberg et al. 2006; Caddy 2011; Ito 2011). This represents just part of an important potential utilization of steel-pipe artificial reefs for management and research purposes. Well-planned artificial reefs designs coupled with the modeling of worst-case scenarios on oceanographic dynamics must be prerequisites for the creation of durable and stable artificial reefs in order to realize the best return on investments for future projects.

The legal context for artificial reef project regulation in Colombia is still developing, as is the scenario in many other countries. Concomitantly, the fishing and environmental policies in Colombia, as well as in other nations, are still weak. Evidence indicates that efforts to manage this kind of large-scale environmental project are increasing, especially in recent years, as are regulatory rules for coastal development activities (e.g., creation of ports, dredging activities, submarine lines, installation of buoys and monobuoys, marinas, groins, and breakwaters). The procedures and requirements for licensing and permitting for artificial reefs deployment in Colombia are consistent with the models and guidelines of different countries across the world (Sayer and Wilding 2002; NOAA 2007; London Convention and Protocol/UNEP 2009; Lindberg and Seaman 2011; Pioch et al. 2011). Owing to growing interest in their application here, it is important that all the institutions involved in this process (Table 2) create a standard protocol or reference terms for artificial reefs deployments focused on Colombian environmental diversity. These protocols should be based on the procedures developed by other countries but modified to accommodate local community (i.e., environmental and civic) differences and requirements. Time demands, if not well managed to obtain all the permits and certifications, can delay the project timeline substantially. This can affect the accomplishment of the objectives and the credibility of participating institutions.

Independent of the intended goals of the specific artificial reef project, it is necessary to conduct research on artisanal fishing dynamics in the proximate area through time. This is because the expected direct or indirect effects of technology, in the long term, are likely to affect general productivity in the area. Fishing dynamics investigations are among the future objectives to improve fishing productivity, coupled with controlled harvesting by artisanal fishermen who potentially will use artificial reef technology.

Changes observed here in species richness and abundance between the pre- and postdeployment assessments attest to the idea that artificial reefs function as habitats that foster the settlement and recruitment of species. This is especially true for artificial reefs with complex vertical structures, relative to faunal diversity (Bohnsack et al. 1991; Rilov and Benayahu 2002; Delgadillo-Garzón et al. 2004). The number of species recorded here was relatively high in relation to the low sample effort and brief deployment. Many artificial reefs and habitats in the Colombian Caribbean were evaluated after longer deployment periods, but the richness and abundance of species here were comparable (Delgadillo-Garzón et al. 2004; Delgadillo-Garzón 2009). The preliminary outcome here indicates that the associated biotic assemblage responds positively to their interaction with the high structural complexity of the habitats in terms of volume, geometry, and holes, along with the area's high productivity and diversity, mentioned earlier. Therefore, these artificial reefs are a promising alternative for successful habitat enhancement in the environmental conditions described here. Long-term scientific monitoring will help to determine the fulfillment of the artificial reef objectives and cost-benefits of the project.

The presence of endangered and commercial species associated with the artificial reefs reinforces their significance in conservation. Moreover, the diversity of fishes and mobile macroinvertebrates (some of these common inhabitants of coral reefs) and the increasing complexity of the sessile biota suggest the potential these structures may have in the future development of ecotourism. Likewise, the application of specifically designed artificial reefs to provide protection, food, and survival for the recorded organisms and other target species will help to achieve the previously mentioned goals.

Recreational diving is increasing worldwide. Fortunately, it is an activity that appears to satisfy conservation targets and economic interests, as stated by Lindberg and Seaman (2011), Shani et al. (2011), and Kirkbride-Smith et al. (2013). Additionally, artificial reef deployments can add to the income of local community beyond that offered by commercial fishing (Brock 1994). This subject is very sensitive in the area of Santa Marta, which has experienced an expansion in recreational diving business and ecotourism, as these activities have been traditionally conducted inside a marine protected area, the Tayrona National Natural Park. Thus, if reef deployment is undertaken in other areas, the technology can be palliative when reducing the recreational diving pressure on natural coral reefs. The growing hotel infrastructure in Pozos Colorados Bay suggests the promising use of artificial reefs as an ecotourism alternative to the bay's actual social and environmental conditions. This technology is considered a good solution to support productive sustainable models for the diversification of fishermen's economy through an interaction with the tourism industry.

In short, there is evidence of the potential for habitat enhancement in an integrative concerted approach, aimed at marine and coastal management. The guidelines for reef development needs to incorporate the prolonged assessment of artificial reef performance (e.g., designs, fishery, ecology, biology, and oceanography) coupled with socioeconomic investment. Additionally, the stewardship of the artificial reefs by authorities and users should be based on precautionary principles. This may include the conformation of a network of discrete marine reserves as a commitment for future sustainability. Areas of critical coastal advancement and the presence of sensitive ecosystems should be the target of these interventions.

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