Effect of location, design and development time on fishes associated to artificial reefs in Santa Marta region, Colombian Caribbean

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Introduction

Santa Marta region is a highly touristic place with an intense port activity for coal and hydrocarbon trade, as well as a large community of artisanal fishers. Natural habitats and fishery resources have been affected by those and other coastal activities, therefore actually reveal signs of environmental degradation.

In the region, some artificial reefs have been deployed as a conservation tools, while other structures function as diving and fishing sites. The different purposes and locations of the artificial reefs represent an opportunity to assess the potential effects of factors such as site, design, and development time in the fishes assemblages aimed to propose environmental management practices in the area.

Methods

Artificial reef design, location, and study area: Four types of artificial reefs were assessed in two different areas of the Santa Marta region, Six cubic (4.5 x 4.5 x 4.5 m) and six pyramid (3 x 3 x 2.8 m) steel pipe reefs (46 cm diameter) with different number of holes and pipes geometry (five designs) were deployed in Pozos Colorados Bay in 2013 and 2015 respectively, between 10 and 17 m depth **(Figure 1, Figure 2).** This Bay is a barren area mainly compose by mud bottom (73 %) and very fine sand (27 %) with a limited amount of hard substrate and seagrass meadows. The area also receives a heavy runoff from a coastal lagoon and nearby continental sources. On the other hand, in Gaira Bay 10 bucket concrete reefs of 1 m^3 were installed in 2014 at 4 m depth, and an old cargo shipwreck of 30 m long has 30 years at 27 m depth. This Bay is surrounded by coralline formations and rocky shores located between 50 and 400 m from the artificial reefs (**Figure 1; Figure 2).** The general weather conditions comprise a dry season between December and March characterized by the strong influence of the Alisios winds and the presence of an upwelling event, low water temperatures (21 C) and high salinities (37-38). The rainy season between April and November has contrasting conditions with increasing water temperatures up to 28 C and salinity reduction between 33-34, as well as considerable influence of freshwater inputs.

Figure 1. Different designs and field surveys of the artificial reefs deployed in Pozos Colorados and Gaira Bays in Santa Marta region, Colombian Caribbean.

Field survey and data analysis: Fishes assemblages were assessed between May and November of 2016 through random visual census of 30 minutes in regular time intervals of six minutes each one for the steel artificial reefs and concrete reefs, while the shipwreck was surveyed in 50 minutes with five intervals of 10 min (Figure 1). Descriptive and inferential univariate and multivariate statistics: one-way analysis of variance, Kruskal-Wallis test and non-metric ordination NDMS were used to compare richness and abundance of fishes in terms of design, location and time of deployment, as well as to assess the distributional pattern of the fishes assemblages. Transformation of the data were carried out to meet the normality and homoscedasticity requirements.

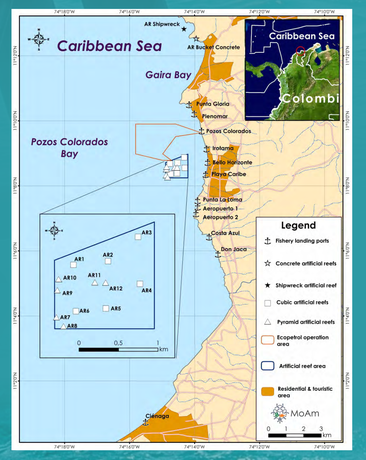

Figure 2. Location of the artificial reefs in the Pozos Colorados Bay and Gaira Bay in the Santa Marta region, Colombian Caribbean.

Results

- A total of 108 species and 11516.5 individuals were recorded including ten endangered fishes such as *Epinephelus itajara*, *Centropomus undecimalis,* and *Lutjanus analis* **(Figure 3).**

Figure 3. Different species of fishes in the artificial reefs: A *Haemulon aurolineatum*, B *Haemulon steindachneri*, C *Opisthonema oglinum*, D *Mycteroperca interstitialis*, E *Odontoscion dentex*, F *Trachinotus goodei*, G *Lutjanus analis*, H *Mycteroperca bonaci*, I *Epinephelus itajara*.

- Concrete and shipwreck reefs showed higher mean richness with 29 (SD±4) and 27.3 (SD±1) species respectively. Mean relative abundance was superior in the wreckage and steel pipe AR1 with 469.1 (SD± 199.7) and 427.3 (SD±176.1) individuals respectively. In general terms, cubic steel artificial reefs deployed in 2013 evidenced higher richness and abundance than pyramid steel deployed in 2015. While the shipwreck and bucket reefs deployed nearby natural habitats showed the highest richness **(Figure 4).**

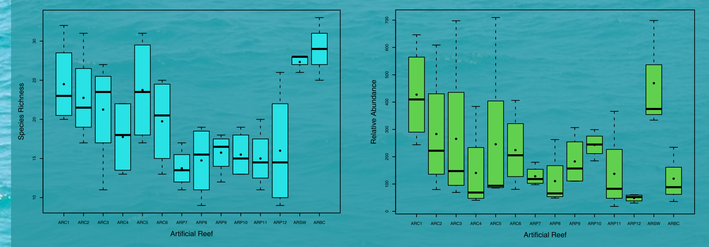

Figure 4. Mean richness and relative abundance in the different type of artificial reefs assessed in Pozos Colorados and Gaira Bays (ARC: steel cubic; ARP: steel pyramid; ARSW: shipwreck; ARBC: bucket concrete)

- The one-way analysis of variance for richness **(Table 1)** and Kruskal-Wallis test for abundance **(Table 2)** showed significant statistical differences for each the assessed factors.

Table 1. One-way analysis of variance (ANOVA) to compare the richness of fishes among different factors (significant statistical differences * p<0.05; **p<0.01).

Factor	Source	SS	DF	MS	F-Ratio	p-value
Artificial reefs	Among groups Within groups	1166.759 1038.667	13 40	89.751 25.967	3.456	0.001**
Location	Among groups Within groups	511.343 1694.083	2 51	511.343 32.579	15.696	0.000**
Design	Among groups Within groups	551.292 1103.958	6 47	137.823 25.673	5.368	0.001**
Year	Among groups Within groups	857.385 1348.04	3 50	137.823 25.673	5.368	0.001**

Table 2. Kruskal-wallis test to compare the relative abundance of fishes among different factors (significant statistical differences * p<0.05; **p<0.01).

Factor	H	DF	p-value
Artificial reefs	24.951	13	0.023*
Location	3.521	2	0.041*
Design	14.13	6	0.007**
Year	4.975	3	0.005**

- In accordance with the previous analysis, the non-metric multidimensional scaling displayed a general segregation of the fishes assemblages corresponding with the different factors of the artificial reefs (stress = 0.1). For instance, the shipwreck and bucket concrete reefs deployed in Gaira Bay were completely separated from the other reefs an each one conformed an independent assemblage, while the pyramid AR11 and AR12 with less amount of holes constituted another aggrupation and showed a similarity of 40 %. A general proximity (20 %) was evident to the remnant 10 steel pipe reefs, which in turn exhibited close similarity for each pair of the pyramid artificial reefs, as well as cubic AR3 and AR5 (80 % similarity), whereas the other cubic reefs performed without a particular pattern **(Figure 5).**

Figure 5. Non-metric multidimensional scaling ordination based on average relative abundance of fishes by artificial reef, the Bray-Curtis similarity matrix and constructed with complete linkage technique (ARC: cubic artificial reef; ARP: pyramid artificial reef; ARSW: shipwreck; ARBC: bucket concrete).

Discussion

- The pattern of richness and abundance of fishes in the artificial reefs regarding the assessed factors supports the idea of high structural complexity (i.e., volume, area, design, vertical profile, holes number) and development time (increased biological complexity and ecological niches) as one of the main drivers of the assemblages, since the older and complex shipwreck exhibited the higher variables, as well as a differentiated community.

- It was also evident how the proximity to natural habitats and the spatial configuration (spread) of the artificial reefs has influence on the diversity of the assemblages, independent of time and complexity, as was the case of the 10 bucket concrete reefs of small volume (10 m^3) but higher richness, nearby rocky and reef formations (50-100 m). However, it seems the abundance in these concrete reefs is modulated by other factors, possibly the volume and vertical profile of the concrete reefs.

- The difference in fishes variables and assemblages between the designs and time of steel pipes reefs also confirmed the effects of structural complexity and biological development with time, as factors that modulate the diversity and distribution pattern of these communities.

- The artificial reefs in the Santa Marta region are one of the most diverse in terms of fishes and endangered species regarding other areas of the Colombian Caribbean such as gas platforms in La Guajira, shipwrecks in Cartagena, and steel pipes in the Gulf of Morrosquillo assessed in similar conditions

- The high diversity of these artificial reefs and their potential contribution to conservation and protection purposes, should be included in the environmental plans of the region, in order to promote sustainable interventions and reliable economic opportunities for coastal communities.

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