# Effects of Artificial Reef Implementation on Fish Populations in a Jamaica Marine Protected Area

# Efectos de la Artificial Reef Aplicación sobre las Poblaciones de Peces en un Área Marina Protegida Jamaica

# Effets de Récif Artificiel Mise en Œuvre sur les Populations de Poissons dans une Zone De Protection Marine de la Jamaïque

DANIEL W. BECKMAN* and JOSHUA H. RUDOLPH

*Missouri State University, 901 S. National Ave., Springfield, Missouri 65897 USA. *danielbeckman@missouristate.edu.*

## ABSTRACT

To alleviate the problem of overfishing and habitat loss, the Jamaican government has implemented measures to assist coral reef associated fish populations rebound and expand. One of these measures was the creation of an artificial reef within Bluefields Bay Marine Sanctuary, a newly created no-take preserve. The purpose of the artificial reef is to provide protection and habitat for fish populations, with an ultimate goal of population expansion beyond the protected zone. This study's purpose was to monitor changes in abundance of fish populations associated with the artificial reef and nearby natural reefs. Two video fish surveys were carried out, approximately six months and twelve months after artificial reef placement. Surveys indicated increases in species richness, abundance, and diversity over the duration of the study at the artificial reef site and at natural reefs in the sanctuary. The increase in fish abundance was most substantial at the artificial reef, with the largest effects reflecting the increase in a single species, the French grunt *Haemulon flavolineatum*. Possible reason for increases included increased dispersal onto reef habitats with protection, seasonal effects, and variability in survey methodology. Further surveys are needed to document successful expansion of reef fish population in this marine protected area.

KEY WORDS: Coral reef, artificial reef, marine protected area

## INTRODUCTION

Threats to coral reef ecosystems throughout much of the Caribbean have significantly altered the fish communities. Predominant threats include increased sedimentation and water pollution, disturbances by coastal development (Agardy and Alder 2007), and overharvest and excessive bycatch of reef-associated species (Appeldoorn et al. 1992). Jamaica's marine resources have been plagued by a series of events in recent decades including hurricanes (Woodley et al. 1989, Hughes 1994), coral disease (Goreau 1992, Green and Bruckner 2000), collapse of the long-spined sea urchin, *Diadema antillarum*, and its poor recovery (Hughes et al. 1985, Edmunds and Carpenter 2001, Dudgeon et al. 2010) and long term serial overfishing (Sary et al. 1997, Carr et al. 2009). Overfishing has been identified by Roberts (1995) to be one of the top three threats to coral reefs. Dive surveys by Munro (1983) and Hawkins and Roberts (2003) found virtually no large groupers or other large predatory fish, revealing the extent of overfishing along the Jamaican coast (Hardt 2009). Loss of large predatory fishes has resulted in the current situation in coral reef ecosystems where fishers harvest various fish species (Aiken and Haughton 1987, Koslow et al. 1988), including juveniles. Klomp's (2003) AGGRA survey of the north and west coast of Jamaica counted more than 6,000 fish and determined a mean length of only 12 cm, also noting that terminal phase male parrotfish over 20 cm were highly uncommon.

One method for assisting the recovery of overharvested reef fish populations is through the implementation of no-take marine protected areas (MPAs). Such areas are established not only to assist with recovery of fish populations within the protected area, but also to aid in the recovery of the entire reef ecosystem and, through a spillover effect, enhance fish communities outside the MPA. Previous studies have shown that fish biomass, size, population density and species diversity can increase in association with the establishment of MPAs (Halpern 2003, Palumbi 2004). Polunin (1999) reported greater fish biomass, species diversity, and abundances within than outside MPA boundaries in Jamaica.

In 2009, a number of Marine Protected Areas were created in Jamaica in an attempt to alleviate problems of severe overfishing. The Jamaica Fisheries Division along with the Ministry of Agriculture declared eight marine sanctuaries. Memorandums of Understanding were established with local community groups (such as Bluefields Bay Fishermen's Friendly Society at the location of this study) which act as co-management entities (UNDP 2010).

Artificial reefs, man-made structures place on the seafloor, are often emplaced to stimulate increases in fish populations. As communities of invertebrates and algae become established, there is an expectation of a subsequent increase in abundances of fish species (McKinley et al. 2011). However, the degree to which artificial reefs can mimic the function of natural living coral reef systems remains questionable; natural reefs have been documented to accumulate more individual fish and a greater species richness (Carr and Hixon 1997). Although there are ongoing debates as to whether artificial reefs act to increase fish populations (enhancement) or simply act as attraction devices for fish already in the area (attraction), fish communities have been documented in numerous cases to colonize artificial reef habitats (Bohnsack et al. 1994, Grossman et al. 1997, Powers et al. 2003).

A no-fishing Marine Protected Areas was established in Bluefield Bay, Jamaica in July, 2009, and 300 *Ecoreef*™ artificial reef modules were put in place within the MPA in July 2011. The goal of this study was to assess and compare fish populations associated with the structures and with natural reef habitat at approximately six and twelve months following the implementation of the artificial reefs.

## METHODS

**Study Site**

Bluefields Bay is located along the southwest coast of Jamaica (Figure 1). Primary currents within Bluefields Bay are from the southeast (Goreau 1992). Jamaica lies in the path of the northwesterly trade winds, and calmer ocean currents are noted between the periods of October and February (Aiken and Kong 2000). The Bluefields Bay Marine Sanctuary, established as a no-take Marine Protected Area in July 2009, is 1359 hectares in area (Figure 1). Bottom habitat in the bay is a mixture of sea grass beds, open sandy areas, and patch reefs. Coral reefs comprise approximately six percent of the MPA, with a clustering of large patch reefs in the back reef zone near the seaward boundary (Carroll 2013). Extensive seagrass beds cover much of the bottom of Bluefields Bay (Goreau 1992), and at the time of this study made up 82% of the benthic area; most of the beds were a mixture of manatee grass and turtle grass. The remaining 12% of the benthic area of the MPA is comprised of sand beds, much of which are in the shallower nearshore areas, predominantly at the northeast end of the bay (Carroll 2013).

Artificial reef structures were installed at N18° 10’18.4” W078°02’34.0” in July 2011 on open sandbed in waters at a depth of approximately 8 m, some of the deepest in the MPA, and located in the proximity of natural reef ecosystems (Figure 2). The artificial reef was made up of 350 modules produced and emplaced by Ecoreefs, Inc. (www.ecoreefs.com). Each module was made up of 30 branches composed of porous textured ceramic material, with fluted surfaces, and designed to superficially resemble staghorn coral (*Acropora cervicornis)*, historically a dominant coral species in Bluefields Bay, but now virtually absent from the area, likely for a variety of undefined reasons. The branches were attached above two settling plates raised above the seafloor, with a central anchor securing the entire structure to the seafloor. Each module weighed 25 kg and was approximately 1 m across and 50 cm tall. Modules were put in place and anchored to the sea floor with rebar by scuba divers with branches immediately adjacent to or interlacing with those of the adjacent module, covering an area of approximately 1,600 square meters in an ovoid shape. All area calculations were made using the Polygon features of ArcGIS.

Four natural reef sections were surveyed for comparison with the artificial reefs. Three were within the sanctuary; Control Reef and Near Reef were within 0.5 km to the northwest and southeast of the artificial reef, respectively; and Edge Reef was approximately 3.5 km northwest of the artificial reef. Moors Reef was outside of the sanctuary, approximately 3 km to the south of the artificial reef. Control Reef covered an area of approximately 60,000 $m^2$, with small sandbeds interspersed along the reef. Surveys were conducted in the extreme northwest portion of the reef. Near Reef displays similar characteristics as Control Reef. Edge Reef is located just inside the sanctuary boundary 3.7 km northwest of the artificial reef, at a depth of approximately 8 m. It is oriented in a southwest to northeast direction and covers an area of approximately 2,100 $m^2$. Moors Reef is a partially exposed shallow reef

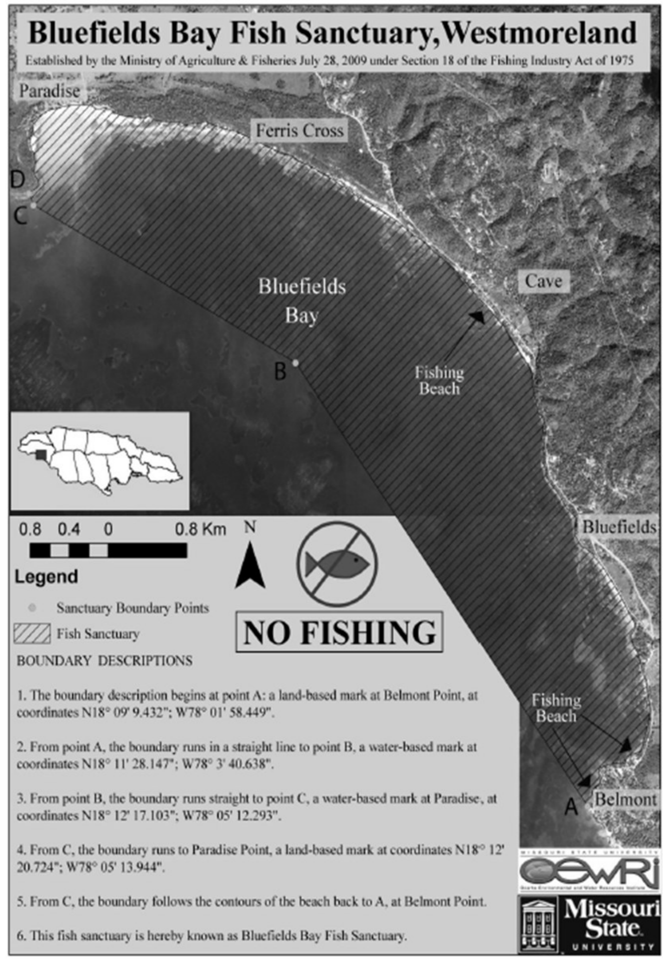


**Figure 1.** Informational map (produced by Ozarks Environment and Water Resource Institute, Missouri State University) providing location and boundary information for the study region in the Bluefields Bay Sanctuary.

outside the sanctuary that is commonly exposed to wave and current activity. Sand flats and coral rubble are interspersed among the patch reefs. January 2012 surveys were carried out during daylight hours with an underwater camera system developed by *SeaViewer™*. The camera was attached at the end of a series of two-inch diameter aluminum poles able to extend up to approximately 11 m beneath the surface. The pole was attached to the side of the boat by a bracket so that the depth of the camera could be adjusted, maintaining it a depth of approximately 2 m from the bottom. The camera view angle could be adjusted from the boat via a rope and pulley system. The camera angle was maintained so that the line of view was approximately 90 degrees relative to the water’s surface. Video transects began at the upcurrent edge of the reef and the boat was allowed to drift with the wind and current over the reefs haphazardly, guided by a snorkeller at the surface to maintain a position over the reef and avoid covering the same area more than once. Three 15-minute videos were recorded sequentially at each site. GPS points were recorded at one-minute intervals.

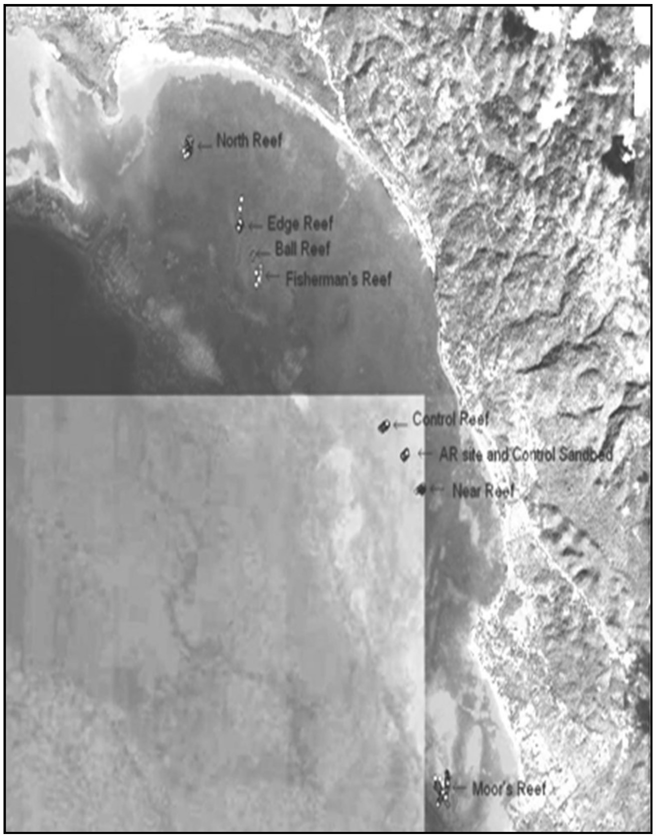


**Figure 2.** Transect site locations in Bluefields Bay, Jamaica. Sample sites were at Moor's Reef, Near Reef, Artificial Reef (AR), Control Reef, and Edge Reef. Figure includes sites not included in this study.

Due to technical difficulties with the *SeaViewer* camera system, survey methodology was modified for the June 2012 surveys. For these surveys a scuba diver swam approximately 2 m above the reef, recording with a portable handheld camera held at arm's length and pointed downward, in an attempt to replicate conditions of the initial survey. The diver swam in concentric patterns progressing from the edge of the reef inwards. A boat, guided by a snorkeler at the surface, maintained a position over the diver to collect GPS data.

Video recordings were analyzed by a single observer, identifying fish species during observation of the video. If identification was uncertain the fish was recorded as *unknown*. Counts of fish by species were tabulated for each date and site. Distances were determined from GIS data using ArcGIS 9.3.1. The average width of view was approximated for each survey method by viewing a selection of video clips. Fish densities by species were calculated as number of individuals per square meter. Species diversity was calculated using the Simpson's Diversity Index, providing a measure reflecting the number of species and how evenly they were distributed numerically in the community. Species richness was as the number of fish species observed.

## RESULTS

During January 2012 surveys, observations were made using the pole-attached camera (remote camera) at the artificial reef and four natural reef sites: Moor Reef (outside of the sanctuary), Control Reef, Near Reef, and Edge Reef (all inside the sanctuary) (Table 1). The number of species identified ranged from 8 at the artificial reef to 29 at Moor Reef. The percentage of fish sighted that were unidentified ranged from 1% at Near Reef to 20% at Control Reef. Data indicated a markedly lower diversity of species and families at the artificial reef in comparison to natural reef sites and a strong similarity among the natural reef sites. Cumulative density of individual fish was considerably higher at the Artificial Reef site; however removing grunts (family Haemulidae) from the data reduced the density by approximately 90%, reflecting a strong dominance of this single family.

During June 2012, surveys were made at the artificial reef and two natural reef sites: Control Reef and Near Reef (Table 2). We were unable to replicate surveys at all sites due to technical difficulties as describe above. Unidentified fish made up 0.1, 1.3, and 0.0 percent of individuals at Artificial, Control, and Near Reef, respectively. Data from June surveys indicated a comparable number of species and families at the artificial reef as the natural reefs. Overall, fish density was higher at the artificial reef site. However, the fish community was dominated by grunts, as indicated by the density values when grunts were excluded. Comparing data between survey dates indicates that values for species richness, family richness, and fish density were greater at all replicated sites during June. Species diversity was higher at the artificial reef site in June, but comparable at the natural reef sites on each date.

Fish density data, tabulated by species, were grouped by family for comparison among sites. January survey data (Figure 3) indicated a dominance of four families at the natural reef sites: grunts (Haemulidae), parrotfish (Scaridae), damselfish (Pomacentridae), and wrasses Labridae). Grunts were at a notably lower density at Moors Reef, the one site outside of the sanctuary. Grunts made up 98% of the fish community at the artificial reef; over 99% of grunts were a single species, the French grunt (*Haemulon flavolineatum* ). June survey data grouped by family (Figure 4) shows a dominance of the same four families plus gobies (Gobiidae) at natural reef sites. At the artificial reef site, grunts made up 93% of the observed individuals, with 99% of grunts being French grunts. Note that snappers, primarily schoolmasters (*Lutjanus apodus*), grey snappers (*Lutjanus griseus*), and lane snappers (*Lutjanus synagris*), although still at a relatively low density, were at a higher density at the artificial reef than at any of the natural reef sites. Most of these, as well as other individuals of large predatory species, were at juvenile life stages. Near Reef and Control Reef indicate similar fish community makeup in June data. Notable differences include a dominance of parrotfish at Control Reef and a relatively low density of wrasses and damselfish at Near Reef.

A comparison of family data between January and June surveys (Figures 3 and 4) suggests a higher density in the dominant families during June, many 2 - 5 times those

**Table 1.** Diversity and density data summary for January 2012 surveys in Bluefields Bay area. All sites but Moors Reef are in the Bluefields Bay Sanctuary.

| | Artificial Reef | Moor Reef | Control Reef | Near Reef | Edge Reef |
|---|---|---|---|---|---|
| Species Richness | 8 | 29 | 27 | 27 | 26 |
| Simpson Diversity Index | 6.7 | 79.7 | 86.8 | 79.6 | 88.2 |
| Family Richness | 5 | 10 | 14 | 15 | 13 |
| Density (N/m$^2$) | 0.92 | 0.19 | 0.21 | 0.18 | 0.21 |
| Density (N/m$^2$) excluding grunts | 0.02 | 0.18 | 0.18 | 0.12 | 0.18 |

**Table 2.** Diversity and density data summary for June 2012 surveys in Bluefields Bay. All sites are in the Bluefields Bay Sanctuary.

| | Artificial Reef | Control Reef | Near Reef |
|---|---|---|---|
| Species Richness | 37 | 50 | 39 |
| Simpson Diversity Index | 15.0 | 84.7 | 75.9 |
| Family Richness | 17 | 15 | 17 |
| Density (N/m$^2$) | 2.21 | 0.69 | 0.33 |
| Density (N/m$^2$) excluding grunts | 0.15 | 0.58 | 0.28 |

of January samples. The same families, however, dominated in January and June. The estimated density of gobies increased over ten times from January to June surveys. Families that would include piscivores and apex predators were at low densities at all sites during both survey periods. Serranids (seabass) were predominately hinds (*Epinephalus* spp.) and hamlets (*Hypoplectrus* spp.). No groupers were documented in any of the surveys. Lutjanids (snappers) were predominately schoolmasters and grey, lane, and yellowtail snappers.

## DISCUSSION

The low species diversity at artificial reef sites could be explained by a number of factors. Additional time may be needed for recruitment of a more diverse assemblage of fishes; however, without living reef habitat, cover and food resources required for many reef-associated species are unavailable. The grunts, and to a lesser degree snappers, that colonized the artificial reef have been documented in other studies to show a rapid colonization of artificial reefs (Bohnsack 1985). These species are predominantly invertivores; there was a lack of piscivorous fishes and apex predators in both the artificial reef and natural reef habitats during this study. The fish families that dominated the natural reefs are common to natural reef habitats throughout the Caribbean. We do not have adequate data to explain observed differences in the makeup of species and families among the natural reef sites.

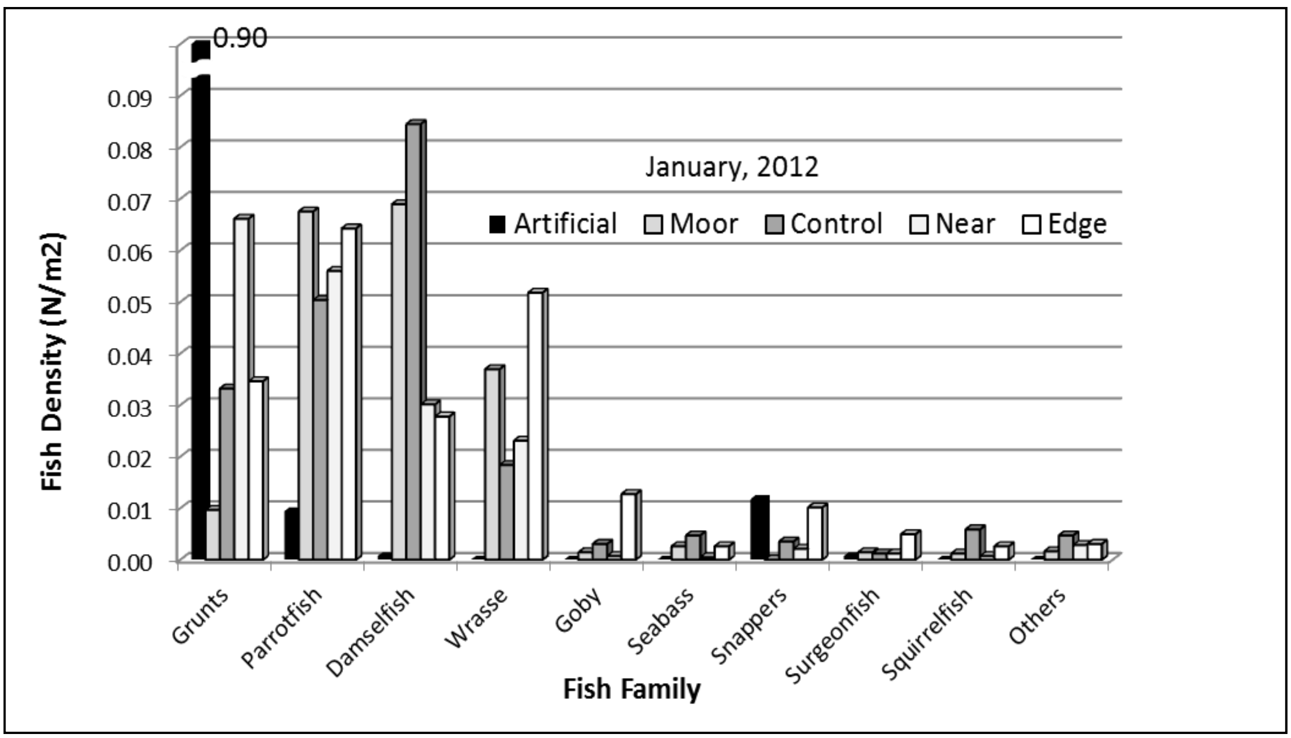


**Figure 3.** Fish density estimates by family at reef sites surveyed in January 2012. The most prevalent families include grunts (Pomadasyidae), parrotfishes (Scaridae), damselfishes (Pomacentridae), wrasses (Labridae), gobies (Gobiidae), seabasses (Serrandiae), snappers (Lutjanidae), surgeonfishes (Acanthuridae), and squirrelfishes (Holocentridae). "Others" include a cumulative data for species in the 14 other families seen in surveys.

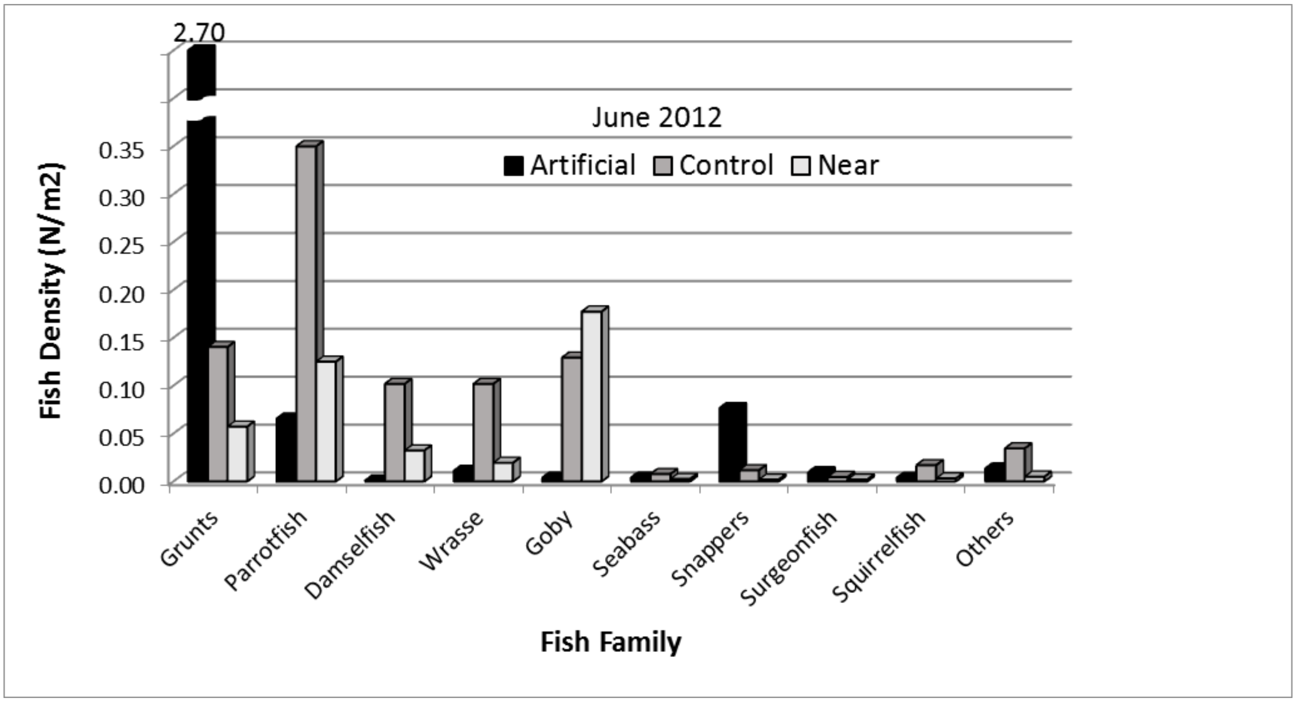


**Figure 4.** Fish density estimates by family at reef sites surveyed in June 2012. "Others" include a cumulative data for species in the 14 other families seen in surveys.

One possible explanation of the apparent increase in densities of most species in the natural reef habitats over the course of the study is that there was additional recruitment, possibly resulting from protections provided by the sanctuary designation. However, potential confounding variables make it impossible to conclude cause-and-effect relationships. The switch in survey methodologies introduced potential bias. Although we attempted to adapt the diver camera survey methodology (July surveys) to match the remote camera surveys (January surveys), factors such as image resolution and potential reactions to the diver (though not apparent) could have biased survey data. Seasonal changes in fish densities could also have affected the results.

The degree of sanctuary protection cannot be determined with presently available data. Although the designation of Bluefields Bay as a no-take sanctuary had been in place approximately 2.5 to 3 years at the time of the January and June 2012 surveys, the degree of enforcement has not been documented. During the survey period, several fish traps were found in the sanctuary (Rudolph 2012), though not in the region associated with the artificial reef site or the natural reef sites surveyed in June sampling (Control Reef and Near Reef). At the artificial reef, the apparent increase in fish densities was substantial enough (threefold for grunts and over fivefold for parrotfish and snappers; Figures 3 and 4) that they likely indicate additional recruitment to the artificial reef over this six month time period. At the time of our January and June surveys the artificial reefs had been in place for six and twelve months, respectively.

Additional surveys would provide valuable information regarding the changes in fish populations at the artificial reef and natural reef sites surveyed in this study. Standardization of survey techniques in future surveys would allow stronger statements about the community that is recruiting to the artificial reef. With scientific documentation of the degree of enforcement of the no-take restrictions in the sanctuary, as well as improved standardization of survey techniques, one could evaluate the changes in the fish population attributable to the establishment of Bluefields Bay as a marine protected area.

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