ROCK ARMOUR: A BENTHIC HABITAT PROVIDING VALUABLE ECOSYSTEM SERVICES IN THE CARIBBEAN SEA

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ABSTRACT

This paper describes our findings from ecological surveys at several shoreline and beach enhancement projects in the Caribbean. Using standard fish abundance and diversity surveys and benthic habitat mapping protocols, we track how rock armour transitions from a barren substrate at installation to a diverse marine ecosystem over time. The ecosystem services provided by the rock armour have been evaluated and compare well with naturally occurring habitats. Using available economic benefit analyses, we estimate the value of these ecosystem services at various stages as the rock armour habitat matures.

BACKGROUND

The tropical coastal zones of the Caribbean Sea face a wide range of natural and anthropogenic stressors including hurricanes, declining fish stocks, and tourism-related development. Coastal erosion has reduced historically narrow setbacks and buffers, leading to the widespread use of coastal protection structures. Public perception of these structures is often polarized, with some stakeholders opposed to hard structures, while others prioritize their usage to reduce coastal erosion and flooding. In general, most Coastal Engineers do not consider ecosystem benefits when developing designs. There is increasing recognition, however, that these habitats can play important ecological roles. These include the development of increased habitat complexity, heterogeneity, and availability in areas that are typically dominated by soft sediments (Burt et al 2012), or that have suffered from environmental degradation/damage. The purpose of this study was therefore to examine the habitat enhancing properties of breakwaters having different ages, and to look at their ability to function as habitat for reef fish communities and marine benthos.

METHODS

Six coastal protection structures (emergent and submerged armour stone breakwaters and groynes) in three Caribbean islands (St. Lucia, Jamaica, and Barbados) were assessed in the study. These structures range in age from 0.5 to 45 years. All structures were built on substrate that was primarily sandy, or pavement with limited coral coverage. Rapid benthic and fish surveys were conducted at each locality to ascertain species abundance, richness and overall characteristics of these systems. The investigations also sought to shed light on the following:

1. Do fish inhabit these structures?
2. How long before natural coral growth occurs?
3. Does the rugosity of the structure matter?
4. Are emergent structures as successful as submerged?
5. Are the created habitats diverse?

Each locality was analyzed using the value transfer method of natural resource valuation to determine the value added. Economic values for ecosystem services were estimated by comparing information collected from similar sites.

RESULTS

Table 1 outlines the observations made at different sites throughout the Caribbean between 2018 and 2020.

Table 1 - Observed coral species, counts and sizes, fish species and counts at 6 sites where rock armoured coastal structures were built.

Location	Age (yrs)	Corals		Fish
		Species/ count	Max. size (cm)	Species/ count
Cap Estate, St. Lucia	0.5	0	N/A	30+/ 100+
Cap Estate, St. Lucia	1.5	0	N/A	30+/ 100+
Negril-A, Jamaica	2	2	<10	20+/ 400+
Negril-A, Jamaica	5	5	10	Not counted
Montego Bay-A, Jamaica	6	6/ 200+	40	27+/ 800+
Negril-B Jamaica	7	5/ 50+	20	15+/ 300+
Accra, Barbados	25	10+/ TNTC	40	25+/ 1000+
Montego Bay-B, Jamaica	45	10+/ TNTC	70	15+/ 100+

The youngest site (Figure 1 - Cap Estates, St Lucia) had more than 30 species of fish and hundreds of individuals including juveniles and adults up to 30cm in size. The adult fish likely migrated from other sites. Algae was the dominant benthic cover, and no corals were observed. One year later, there were different types of algae covering the rock armour, although no corals were observed.

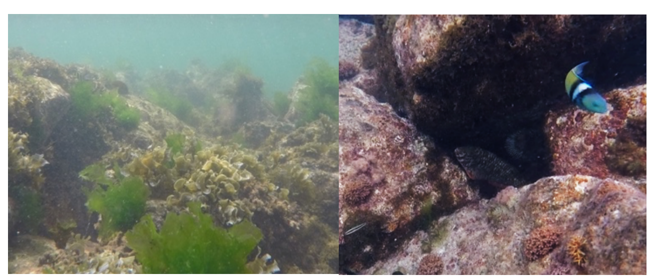

Figure 1 – Submerged breakwater in St Lucia. Age=0.5yr (left); 1.5yr (right).

Figure 2 depicts a rock armour substrate at 2 years age and shows various fish species and numbers. Coral species and size was small. After 5 years, the number of coral species increased to 5 and the sizes were 10cm and larger, as shown in Figure 2.

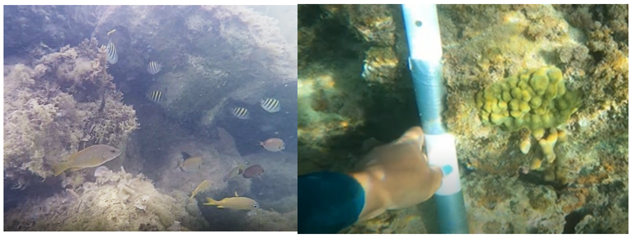

Figure 2 – Groyne in Negril-A. Age=2yr (left); 5yr (right)

At 6 years age (Figure 3) 27 fish species were observed with more than 800 individuals including many juveniles, especially in the crevices between rocks. Coral clusters up to 20cm in diameter were observed along with urchins, other invertebrates, and lobsters.

Figure 3 – Artificial reef clusters in Montego Bay-A. Age=6yr

At the mature sites (Accra [25 year], and Montego Bay-B [45 years]) species richness, amongst fish and corals was high and thousands of individuals were observed including mature and juveniles. Gorgonians and sponges were observed in high abundance, as shown in Figure 4. Macrofauna such as hawksbill turtles and various invertebrates were also observed living within and around the structures.

Figure 4 – Submerged breakwater at Accra. Age=25yr

In general, recorded observations demonstrate that within several months, rock armour becomes an important habitat for fish and within a few years (2-5) these structures can promote fish and coral abundance and species richness comparable to that of natural coral reefs. Fish and invertebrates of all demographic stages use these coastal defense structures as habitat, and coral and other species such as gorgonians and sponges use them for recruitment. Observations from nearshore coral reefs in Jamaica and Barbados suggest that the species number and count for corals and fish are similar to those observed at Montego Bay-B and Accra.

Based on these limited observations, we estimate that rock armour approximately increases from barren at installation to 20% of the coral and fish habitat characteristics of nearby reefs in 2 years; after 5 years it is around 50% and at 20+ years age achieves 90%.

ECOSYSTEM SERVICES

Tropical coral reefs are known to provide a wide range of ecosystem services (Hicks et al 2019). Using the Millennium Ecosystem Assessment (MEA, 2005) categories, coral reefs provide supporting, regulating, provisioning, and cultural services as outlined in Table 2 (Moberg and Folke, 1999).

Table 2 – Ecosystem services provided by coral reefs

MEA Category	Ecosystem Service	Example
Supporting	Biodiversity Habitat	Tropical coral reefs are very biodiverse ecosystems. The structural complexity of reefs provides important habitat.
Regulating	Coastal Protection, Water Quality	Across reef coastlines annual expected damage is reduced by $4billion (Beck, 2018)
Provisioning	Fishery, Materials	Fish provide vital nutrition to many coastal communities.
Cultural	Cultural, Reef Tourism	Globally, reef tourism is worth $38.5 billion/yr. (Spalding et al, 2017)

Observations made on the rock armour suggest that these structures can provide at least some of these ecosystem services. Biodiversity and habitat were observed in a limited way at the younger structures and were noticeably richer for the older structures. Coastal protection is inherently included in these engineered structures. Therefore, including this as an ecosystem service of the rock armour would essentially be double counting the benefit. The number of species and individuals observed on the older structures suggests that fish biomass has increased in the location of the rock armour, and the inclusion of juveniles and adults suggests that, at least for the older structures, this does not represent a relocation from other habitats. Reef tourism provides a significant monetary contribution to local economies.

Spalding et al (2017) mapped the global value of coral reef tourism, which totaled US$36 Billion. Within the Caribbean contributions range from $200 to $29,000 $ha^{-1}y^{-1}$ as shown in Table 3.

Table 3. - Mean value of reef tourism for different countries within the Caribbean Sea from Spalding et al (2017).

Country/ Territory	Total reef-associated visitor expenditure (US$million)	Mean Value of reef (US$ $ha^{-1}y^{-1}$)
Anguilla	20	3,800
Antigua and Barbuda	66	5,700
Aruba	218	22,000
Bahamas, The	526	1,300
Barbados	180	29,000
Belize	81	500
BVI	196	7,300
Cayman	293	12,700
Cuba	283	600
Dominican Republic	512	6,100
Grenada	23	2,000
Guadeloupe	90	3,300
Haiti	15	200
Honduras	447	4,200
Jamaica	333	4,400
Martinique	89	5,800
Mexico	3,000	20,300
St Kitts and Nevis	16	2,000
St Lucia	57	9,400
St Vincent	25	2,900
Trinidad and Tobago	45	6,000
Turks and Caicos Is.	98	2,800
US (Florida)	1,157	9,800
US (Puerto Rico)	649	13,800
US (Virgin Islands)	276	20,600
Mean		**7,800**

Cesar et al (2003) estimated the annual contribution of coral reefs to be US$30billion broken down according to different ecosystem services (Figure 5). This suggests that reef tourism represents approximately one third of the total. Using this ratio and the mean reef tourism value ($7,800) but excluding coastal protection as an ecosystem service, rock armour could achieve a total annual contribution of $17,000 $ha^{-1}y^{-1}$ for sites within the Caribbean Sea.

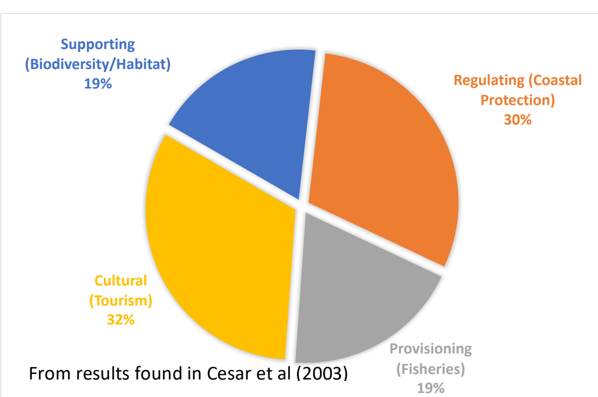

Figure 5 - Breakdown of ecosystem services of coral reefs

By considering the increasing contribution over the first 20 years, and assuming an internal rate of return of 3% for a 50-year time span, we have estimated the Net Present Value of the average ecosystem services provided by rock armour in the Caribbean Sea to potentially be $300,000 ha^{-1}. For a typical breakwater this may equate to $300-450 per metre of length. It should be stressed that there could be considerable range to this value depending on the country/territory considered.

CONCLUSION

Comparisons with the ecosystem benefits of natural habitats show that rock armour can become healthy diverse functioning ecosystems within a span of approximately 20 years. One key reason for this is that appropriately sized armour creates a more stable, rugous and complex habitat than a substrate that is mobile (rubble, sand, etc.). Using an increasing ecosystem services function over a 50-year timespan, we estimate the NPV of rock armour to be approximately $300,000 ha^{-1} [$300-450 per metre length of a typical nearshore submerged breakwater]. Although not traditionally seen as an ecosystem-based adaptation measure, over a short period of time rock armour can become a vibrant contributor to the marine ecosystem that has tangible positive benefits.

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