THE GIBRALTAR ARTIFICIAL REEF: HABITAT MANIPULATION.

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Resumen.

Hace unos veinte años se comenzó a trabajar en la construcción de un arrecife artificial en las aguas de Gibraltar. Se dan detalles de la localización, el desarrollo de los métodos empleados y la ampliación en la población de las especies marinas que lo utilizan.

Summary

Almost twenty years ago work started on the building of an artificial reef offshore reef in Gibraltar. Details of the site, the development of the construction techniques and the increase in the number of marine species making use of the area are given.

Rising sharply at the threshold of the Mediterranean, Gibraltar has a natural bay of some 16 km^2 that has been used by Man for many centuries for its marine life as well as safe anchorage in the "Non Plus Ultra" of the ancients. Here, the Atlantic Ocean feeds less saline waters to the Mediterranean replenishing that lost through evaporation in the hot climate of the area. This mixing is no doubt a source of a rich marine species diversity, both sedentary and pelagic.

As throughout the Mediterranean Sea, the variety of life in the Bay of Gibraltar has been under increasing pressure from Man since early times. Pelagic species that once epitomised the Mediterranean-Atlantic link such as the tuna (*Thunnus*

thunnus), has dropped so alarmingly in numbers due to overexploitation, that it remains a mere semblance of the past (FAO, 1987). Equally, littoral animal and plant diversity in some parts of equivalent richness to tropical seas, have suffered and still endure the onslaught of overfishing and damage to their habitats. Shallow coastal waters in the bay of Gibraltar area have been overfished and dredged so vastly that barren sandy bottom dominates in areas which were once covered with lush meadows of sea grass (*Posidonia* and *Zostera*). Midwater and bottom-dwelling fish have been totally overfished.

Although recovery of sea grass meadows may be more difficult (Shaw 1993), the improvement of marine diversity in the Bay can be achieved by the provision of hard substrates for colonisation of invertebrates and shelter for fish. The construction of artificial reefs in the United States (Unger, 1966; Stone, 1985), Japan (Nakamura, 1986) and in the Mediterranean Sea itself (Bombace, 1989) have been crucial in increasing the potential of these communities. Artificial reefs have been used throughout the world to enhance fishing efforts of anglers and in the United States they have been important for the past 100 years (Stone, 1985). Construction of these structures underwater can be elaborate enterprises as exemplified by those in Conero promontory in Italy (Bombace, 1981) and others which employ concrete modules and cages or fibreglass-reinforced plastic (Sheehy, 1982). However, artificial reef construction can be just as effective but simpler than these with the sinking of discarded vessels and other material. This paper reports on how through the efforts of a small group of divers an artificial reef of some 4.799 m^2, probably the largest in the Mediterranean, was created on the Gibraltar side of the Bay of Gibraltar. Its impact in promoting marine diversity in the region is also assessed.

Location

The site chosen was in Camp Bay on the western side of Gibraltar. This bay was created by the quarrying of stone in the 1800's to provide material for the present day dry docks and sea defense moles. The result has been the generation of a recreational shoreline area with easy access to the sea. The shingle beach moves out to meet the sandy seabed at a depth of 7 m (Fig. 1).

Construction of the Reef

Construction of the reef was carried out over a period of 20 years in three well defined phases. The initial phase began in the winter of 1975 and was a prototype made from old car tyres. This is a medium much favoured for similar projects (Candle, 1986; Bell, 1988). Benthic stones (1-3 kg) were used as ballast to hold the tyres *in situ*. Overall size (length 45 x 2 x 0.5 m), allowing for curvature on the surface undulatory loop, created a surface area of 134 m^2. It took 768 man-hours to completion. A team of three divers with SCUBA equipment aided by one 125 kg lift bag for transporting benthic stones and a 225-1itre plastic drum was used for moving the stones. Rate of construction was one m^2 of reef for every five diving hours with running repairs and relaying of damaged areas included within the same time frame. The second phase of the project was started in 1970s with disused car bodies that were transported to location with the aid of 45 gallon drums as floats and the same basic facilities as Phase one. Rows of car bodies were formed three wide and two high, secured by interlocking them together with chain and shackles. Similar to Phase one this approach was time consuming (700 man-hours). Overall stability was affected by weather conditions (winter storms stripped away much of the structure) and the adverse affects of sea water on metal. Electrolysis of light and heavy metals caused chemical decomposition much faster than was at first anticipated. The assumption that the metallic decomposition would be the same for all car models was not met. Fiat cars had a life span of 6 months while Mercedes-Benz could last up to 48 months.

Following this the overall project was reevaluated. There was a need for a multi-facetted structure that would provide the complexity of a natural habitat but would also: (a) have a long life span until organisms settled; (b) withstand all weather conditions and (c) provide all the advantages of a natural habitat. Any form of shipping would be the only artificial medium that would provide all of these advantages. The multi-facets provided by sunken vessels cover dimensions that are difficult to provide for in one overall structure. The variety of surface areas of both horizontal and vertical aspects with varying degrees of direct and indirect sunlight in summer and winter, sheltered and unsheltered areas throughout the lunar tide cycles which in all provide a complex natural reef. The internal structure also provides a nocturnal environment throughout the 24 hour solar cycle that compliments the outside habitat.

Wrecks have long been known to divers and fishermen alike as areas of great marine diversity both within and without. This added feature provides a habitat with varying shades of indirect light to complete darkness internally, the obverse and the reverse in the one stable structure are provided for.

This third phase of the project started in 1983 and consisted of ten barges ranging from 400 tons to 900 tons, in a depth range from 9-21m providing an overall area of 4799 m^2. The internal surface area can be effectively doubled by the internal bulk heads and decks, thus providing close to 9548 m^2 of a varied habitat on what was hitherto only sandy seabed.

Impact Assessment

An increase in biodiversity became evident within a few weeks of laying out the prototype (Table 2). Several midwater and bottom dwelling species ranged over the area of reef that was completed; overall range extending as the reef progressed. This diversity increased dramatically in sessile and invertebrates when barges became the general medium of the overall project (Table 3). From an overall count of some 112 species from tables 2&3 all species remain present with the exception 6 invertebrates from table 3 being the only losses from the original 33 species listed prior to the project.

The overal increase in species numbers to-date is some 70 plus on visual swim line observations, closer more detailed recording will no doubt swell the list beyound that no recorded.

Plans for the future

With the overall biodiversity throughout the reef structures changing so dramatically and transect studies being carried out at present to prove sustainability throughout, the long term hope is to augment the five barges with a series of Jurrassic limestone deposits, creating natural strata for long term development as the present structures deteriorate with the passage of time.
Further barges will be obtained to extend the overall size of the project. They have so far proved to provide: a medium that is easy to locate *in situ*, colonising within a minimum time frame with little or no disturbance once situated; a breakwater capability that benefits the existing shoreline habitat that was hitherto lacking; a research area with easy access that cannot be over fished by standard methods (trawl and nets), due to their overall size shape and seabed location (see layout 1). Their mariculture facilities provide both commercial and sport fishing facets that could be exploited with the correct management should the need arise. Overall the use of barges that were otherwise bound for the breakers yard and in many cases were a liability to their owners, provide ready made structures with optimum prerequisites for artificial reefs both in size, shape and maximum dimensions, that are not labour intensive and are located with minimum effort at an overall minimum cost. Even

though the more ambitious concrete constructions may look more appealing aethetically they require much more funding and logistic support than the ones described here.

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Table 1. Details of barges used in the construction of the Gibraltar Bay artificial reef.

Barge Nº.	Depth (m)	Weight (tons)	Effective surface area (m^2)
1	9	400	425
2	9	400	425
3	15	600	513
4	21	800	622
5	19	900	891
6	15	600	513
7	10	10	150
8	10	10	150
9	10	250	810
10	20	150	300
TOTALS		4.120	4.799

Table 2. Vertebrates seen in the area before and after the building of prototype reef.

Species Common name	Habitat	Before	After
Red mullet	B	X	X
Yellow gurnard	B	X	X
Red gurnard	B	X	X
Streaked gurnard	B	X	X
Greater weever	B	X	X
Lesser weever	B	X	X
Star gazer	B	X	X
Two bannded bream	M	X	X
Anglerfish	B	X	X
Electric skate	B	X	X
Sole	B	X	X
Gilthead bream	M		X
Saddled sea bream	M		X
Black bream	M		X
Annular bream	M		X
White sea bream	M		X
Common sea bream	M		X
Soldier bream	M		X
Saupe	St		X
Painted comber	B/St		X
Comber	B/St		X
Brown comber	B/St		X
Blacktail comber	St		X
Golden grouper	St		X
White grouper	St		X
Shi drumfish	M		X
Cardinalfish	M		X
Damselfish	M		X
African striped grunt	St		X
Rainbow wrass	M		X
Peacock wrass	M/St		X
Bass	M	X	X
Corb	M		X
Roving grey mullet	M		X
Five spot wrasse	St		X
Ballan wrasse	St		X
Brown wrasse	St		X
Cuckoo wrasse	St		X
Axillary wrasse	St		X
Corkwing wrasse	St		X
Long nosed wrasse	St		X
Goldsinny wrasse	St		X
Scorpion fish	B		X
Blenny (some species)	B/St		X
Goby (some species)	B/St		X
Conger eel	B		X
Moray eel	B		X
Serpent eel	S		X
Trigger fish	M		X
Blue fin tuna	M		X
Bogue	M		X
Picarel	M		X
Mediterranean mackrel	M		X
Mackerel	M		X

Table 3. Invertebrates seen in the area before and after the building of prototype reef.

Species Common name	Habitat	Before	After
Spiny starfish	B		X
Blue starfish	B		X
Red starfish	B		X
Red comb-star	S	X	X
Feather-star	B		X
Brown brittle-star	B	X	
Brittle-star	B	X	
Rock-urchin	St	X	X
Violet sea-urchin	St	X	X
Sea-urchin	St	X	
Long spine urchin	St	X	
Black sea-urchin	St	X	
Edible-urchin	St	X	
Heart-urchin	St	X	X
Sea cucumber	B		X
Tube worm	B		X
Capped tube worm	B/St		X
Sand tube-worm	B	X	X
Peacock-worm	B		
Norway tube-worm	B		X
Bonellia	St		X
Bryozoa sp.	St		X
Bryozoa armata	St		X
White gorgonian	St		X
Deadmans fingers	St		X
Sea pen	S	X	X
Soft coral	St		X
Anemone	St		
Anemone	St	X	X
Star coral	St		
Golden coral	St		X
Coral	St		X
Sea-squirt	St	X	X
Sea-egg	St		X
Leather sponge	St	X	
Lobster	B		X
Squat Lobster	B/St		X
Spider crab	B		X
Crab	B		X
Swimming crab	B/St		X
Conch	B		X
Murex	B	X	X
Fan mussel	B	X	X
Mediterranean mussel	St		X
Scallop	B	X	X
Cowrie	B		X
Ship worm	St		X
Nudibranchia sp.	St		X
Nudibranchia babai	B/St		X
Nudibranchia astromaculata	S/St	X	X
Sea slug	St		X
Cuttle fish	M	X	X
Octopus	B	X	X
Lesser octopus	B	X	X
Green turtle	S/M		X

Key to Table 3 **B** = Bottom. **M** = Midwater. **St** = Strata. **S** = Sand. **X** = Present

Appendix I.-

List of vertebrates (Common and scientific names)

Red mullet (*Mullus barbatus & Mullus surmuletus*)
Yellow gurnard (*Trigla lucerna*)
Red gurnard (*Aspitrigla cuculus*)
Streaked gurnard (*Trigloporus lastoviza*)
Greater weever (*Trachinus draco*)
Lesser weever (*Trachinus vipera*)
Star gazer (*Uranoscopus scaber*)
Two banded bream (*Diplolodus vulgaris*)
Anglerfish (*Lophius piscatorius*)
Electric skate (*Torpedo marmorata*)
Sole (*Solea solea*)
Gilthead sea bream (*Sparus aurata*)
Annular bream (*Diplodus annularis*)
White sea bream (*Diplodus sargus sargus*)
Common sea bream (*Diplodus vulgaris*)
Saddled sea bream (*Oblada melanura*)
Axillary sea bream (*Pagellus acarne*)
Black sea bream (*Spondyliosoma cantharus*)
Soldier bream (*Diplodus cervinus*)
Saupe (*Boops salpa*)
Painted comber (*Serranus scriber*)
Comber (*Serranus cabrilla*)
Brown comber (*Serranus hepatus*)
Blacktail comber (*Seranus atricauda*)
Golden grouper (*Epinephelus alexandrinus*)
White grouper (*Epinephelus aeneus*)
Cardinalfish (*Anthias anthias*)
Damselfish (*Chromis chromis*)
Shi drumfish (*Umbrina cirrosa*)
Rainbow wrasse (*Coris gulis*)
Peacock wrasse (*Thalassoma pavo*)
African striped grunt (*Parapristipoma octolineatum*)
Bass (*Dicentrachus labrax*)
Corb (*Sciaena umbra*)
Roving grey mullet (*Liza carinatal*)
Goldsinny wrasse (*Ctenolabrus rupestris*)
Five spot wrasse (*Crenilabrus quinquemaculatus*)
Ballan wrasse (*Labrus bergylta*)
Bryozoa (*Schismopora armata*)
Brown wrasse (*Labrus merula*)
Cuckoo wrasse (*Labrus mixtus*)
Axillary wrasse (*Crenilabrus mediterraneus*)
Corkwing wrasse (*Crenilabrus melops*)
Long nosed wrasse (*Symphodus rostratus*)
Picarel (*Spicara smaris*)
Mediterranean mackerel (*Trachurus mediterraneus*)
Mackerel (*Scomber sconmbrus*)
Scorpion fish (*Scorpaena porcus*)
Blenny (*Blennius* species)
Goby (*Gobius* species)
Conger eel (*Conger conger*)
Moray eel (*Muraena helena*)
Serpent eel (*Ophisurus serpens*)
Green turtle (*Chelonia mydas mydas*)
Trigger fish (*Balistes capriscus*)

List of invertebrates (Common and scientific names).

Spiny star-fish (*Marthasterias glacialis*)
Blue star-fish (*Cosinasterias tenuipina*)
Red star-fish (*Echinaster sepositus*)
Comb star (*Astroecten aurantiacus*)
Feather star (*Antedon mediterranea*)
Brown brittle-star (*Ophioderma longicauda*)
Brittle star (*Ophiothrix fragilis*)
Rock urchin (*Parocentrotus lividus*)
Violet sea-urchin (*Sphaerechinus granularis*)
Sea-urchin (*Echinus acutus*)
Ling-spine urchin (*Centrostephanus longispinus*)
Black sea-urchin (*Arbacia lixuca*)
Edible urchin (*Echinus esculentus*)
Heart urchin (*Echinus acutus*)
Sea cucumber (*Holothuria forskali*)
Tube worm (*Spirographis spallanzanii*)
Capped Tube worm (*Serpula vermicularis*)
Sand tube-worm (*Myxicola infundibulum*)
Peacock worm (*Sabella pavonina*)
Norway tube-worm (*Hydroies norvigica*)
Bonellia (*Bonellia viridis*)
Bryozoa (*Frondipora reticulata*)

Comunicaciones

White gorgonian (*Eunicella verrucosa*)
Deadmans finger (*Alcyonium palmatum*)
Sea-pen (*Veretillum cynomorium*)
Soft-coral (*Parerythropodium coralloides*)
Sea-anemone (*Cerianthus membranaceus*)
Anemone (*Peachia hastata*)
Anemone (*Alicia mirabilis*)
Star-coral (*Astroides calycularis*)
Coral (*Cladocora cespitosa*)
Golden-coral (*Balanophyllia regis*)
Coral (*Balanophyllia italica*)
Sea-squirt (*Clavelina lepadiformis*)
Sea-egg (*Microcosmus sulcatus*)
Squirt (*Diazona violacea*)
Leather sponge (*Chondrosia reniformis*)
Lobster (*Scyllarus arctus*)
Lobster (*Scyllarides laus*)
Spider-crab (*Maja squinado*)
Fan mussel (*Pinus nobilis*)
Mussel (*Mytilus galloprovincialis*)
Scallop (*Pecten jacobaeus*)
Crab (*Calappa granulata*)
Swimming crab (*Macropipus depurator*)
Canch (*Trionium nodiferum*)
Murex (*Murex brandaris*)
Murex (*Murex truncatus*)
Cowrie (*Cypraea pyrum*)
Ship-worm (*Teredo navalis*)
Nudibranchia (*Flabellina babai*)
Nudibranchia (*Pectodoris atromaculata*)
Sea-slug (*Flabelina affinis*)
Nudibranchia (*Oscaniuis tuberculatus*)
Cuttle-fish (*Sepia officinalis*)
Octopus (*Octopus vulgaris*)
Lesser octopus (*Fledone cirrhosa*).