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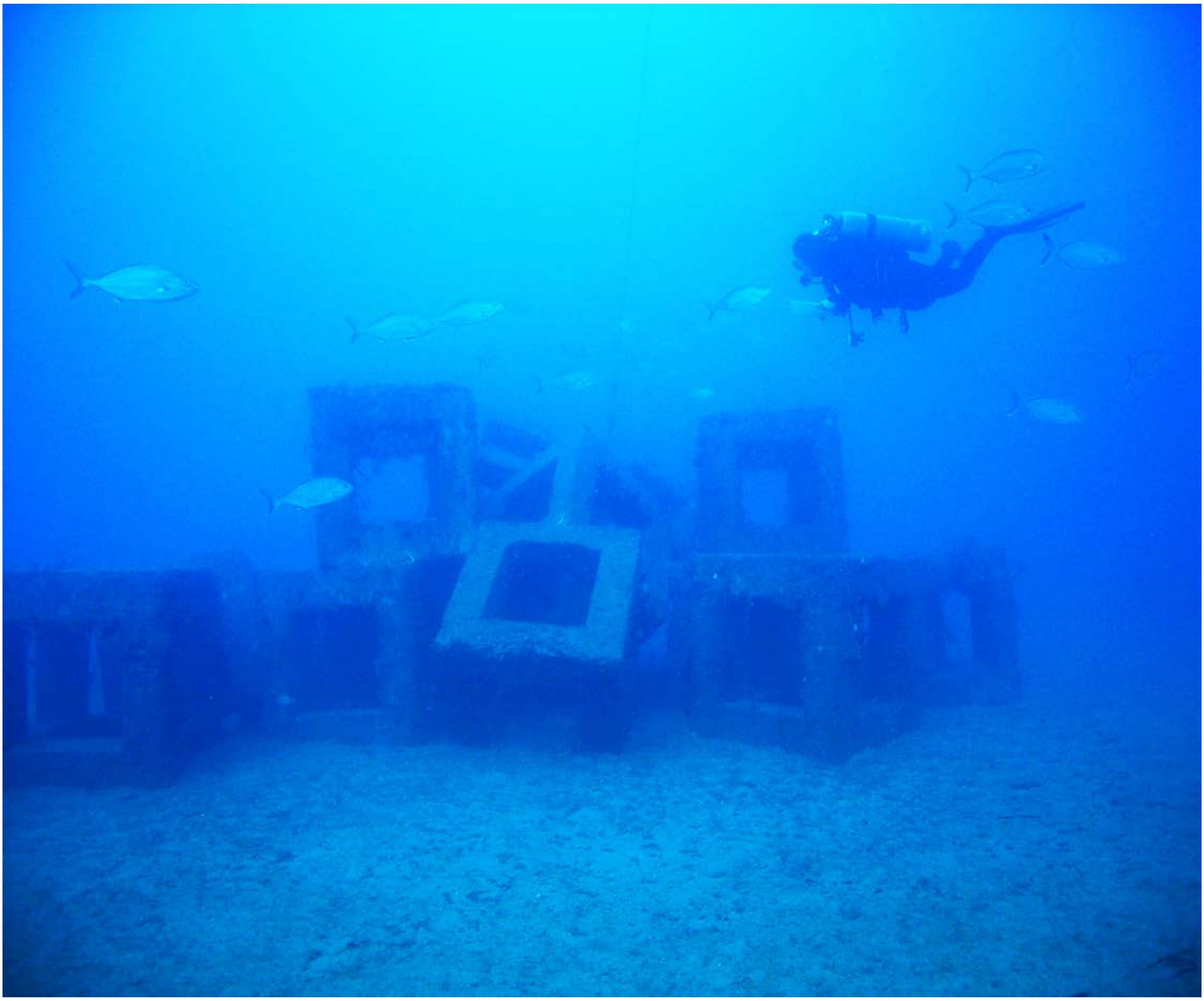
PRACTICAL GUIDELINES FOR THE USE OF ARTIFICIAL REEFS IN THE MEDITERRANEAN AND THE BLACK SEA



GENERAL FISHERIES COMMISSION FOR THE MEDITERRANEAN

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GENERAL FISHERIES COMMISSION FOR THE MEDITERRANEAN

PRACTICAL GUIDELINES FOR THE USE OF ARTIFICIAL REEFS IN THE MEDITERRANEAN AND THE BLACK SEA

by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 2015

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PREPARATION OF THIS DOCUMENT

This publication is part of the Studies and Reviews series of the General Fisheries Commission for the Mediterranean (GFCM), which includes scientific and methodological papers on different topics of interest for the GFCM in the field of fisheries and aquaculture. This document contains guidelines on management practices for the planning, siting, construction, anchoring and monitoring of artificial reefs in the Mediterranean and the Black Sea. It is intended to provide users, managers and planners with essential information and guidance on some of the most effective methods for enhancing and protecting natural resources while increasing fisheries and aquaculture opportunities. Acknowledging the increasing interest shown by several Mediterranean countries in artificial reefs, the GFCM has agreed to compile up-to-date guidelines with a view to supporting potential artificial reef developers in the set-up, monitoring and management of artificial reefs in Mediterranean and Black Sea coastal waters. These guidelines were presented in January 2012 at the twelfth session of the GFCM Subcommittee on Marine Environment and Ecosystems (SCMEE) and further discussed during a workshop on artificial reefs in the Mediterranean and the Black Sea, held on the occasion of the tenth International Conference on Artificial Reefs and Aquatic Habitats (September 2013, Izmir, Turkey). This document is the fruit of cooperation between several scientists from different countries having specific experience in artificial reefs and it builds upon the recommendations included in international conventions and previous guidelines.

ACKNOWLEDGEMENTS

This publication is the result of a team work and could not have been completed without the precious inputs of the many experts who provided materials and information on artificial reefs deployed in their own countries. Special thanks are addressed to Dr Heath Folpp from the New South Wales Department of Primary Industries (NSW DPI), North Coast Fisheries, NSW Australia, and Dr Michael Lowry from NSW DPI, Port Stephens Fisheries Institute, NSW Australia, who kindly peer-reviewed the earlier drafts of this document and provided precious and helpful suggestions and information. Finally, gratitude is expressed to the GFCM Secretariat, namely the Executive Secretary, Mr Abdellah Srour, and his team, Ms Pilar Hernandez and Ms Aurora Nastasi, for their commitment in publishing this work.

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ABSTRACT

Artificial reefs have been used for a long time around the world and have served many purposes ranging from habitat restoration, fish stock enhancement and fisheries management to research and recreation. At present, fish stock enhancement and fisheries management are the main reasons driving reef construction in the Mediterranean Sea, while habitat restoration is the main purpose for their use in the Black Sea. The increasing interest for artificial reefs has given rise to several concerns regarding their possible negative impacts, due to the use of unsuitable materials and to waste dumping. Consequently, the need emerged over the past fifteen years to develop guidelines in order to support managers and scientists in the use of artificial reefs in European seas. Based on such existing guidelines, this document aims to further provide up-to-date information and guidance regarding specific management practices for the planning, siting, construction and anchoring of artificial reefs in the Mediterranean and the Black Sea and for monitoring their effectiveness from an ecological and socio-economic point of view.

After providing an overview of existing definitions and legislations relating to the deployment of artificial reefs, this document illustrates the main aspects related to the different steps involved in the planning, siting and construction phases. A detailed presentation of the specific types and purposes of artificial reefs follows, with a description of their possible impacts and of existing methodologies to monitor and assess their effectiveness. Finally, these guidelines give insights about the socio-economic effects of artificial reefs and control, surveillance and maintenance issues.

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1. Introduction

Historically, artificial reefs have been used around the world to attract fish and facilitate its capture for human consumption. In the Mediterranean Sea, there is evidence that the first artificial reefs were inadvertently created in the 1500s. At that time, the rocks used to anchor tuna fishing nets were left on the seabed at the end of each fishing season. These anchors accumulated over time and created new rocky habitats that became inhabited by fish which were subsequently exploited by local fishers between the tuna fishing seasons (Riggio *et al.,* 2000). Throughout history, it is likely that similar practices have been employed by artisanal fishers across the world (Simard, 1995).

The modern concept of artificial reef appeared in Japan during the 20th century, after World War II, and has been adopted in the Mediterranean in the second half of the 1900s. To date, around 300 artificial reefs are deployed in the Mediterranean and the Black Sea and their main purpose is to enhance fisheries and improve fisheries management.

The increasing interest for artificial reefs has given rise to concerns regarding possible negative impacts caused by the use of unsuitable materials and the dumping of waste. Consequently, during the past fifteen years, the need has emerged to develop guidelines to support managers and scientists in the placement of artificial reefs in the European seas (OSPAR Commission, 1999 and 2009; UNEP-MAP, 2005; London Convention and Protocol/UNEP, 2009).

In 2009, the General Fisheries Commission for the Mediterranean (GFCM) of the Food and Agriculture Organization of the United Nations (FAO) initiated a debate on the use of artificial reefs in the Mediterranean and the Black Sea, in particular to enhance and manage fisheries and fishing resources (GFCM, 2010). This issue was addressed during the annual sessions of the GFCM Subcommittee on Marine Environment and Ecosystems (SCMEE) leading to an ad hoc workshop in January 2011 (GFCM, 2011 and 2012). Acknowledging the increasing interest shown by several Mediterranean countries towards artificial reefs, the workshop concluded, among others, that updated guidelines to support potential artificial reef developers would be needed to establish and monitor artificial reefs in the coastal waters of the Mediterranean and the Black Sea.

This document aims at providing the best and most generally accepted guidelines regarding management practices for artificial reef planning, siting, construction, anchoring and monitoring in the Mediterranean and the Black Sea. These guidelines will provide users, managers and planners with essential information and guidance on the most effective methods for enhancing and protecting natural resources as well as for improving fisheries and aquaculture opportunities.

The objectives of these guidelines are to:

- update the information reported in previous guidelines;
- assist countries in the planning and deployment of artificial reefs on the basis of scientific criteria;
- avoid the pollution or degradation of aquatic ecosystems due to the deployment of unsuitable materials and waste dumping;
- prevent possible negative impacts caused by the deployment of artificial reefs;

- provide information on the different scopes and types of artificial reefs, as well as on their potential effects;
- provide technical information on the deployment, monitoring, management and socio-economic effects of artificial reefs.

The chapters below provide a definition of artificial reefs as well as a list of the technical terms that are used in the document and should be employed when referring to artificial reefs. The main reasons for which artificial reefs are usually constructed are also explained. The subsequent sections address aspects related to international legislation, planning, siting, materials, design and placement, including several examples of artificial reef construction in the Mediterranean Sea. Finally, possible negative impacts as well as suggestions to facilitate the standardization of monitoring methodologies and appropriate management are illustrated.

1.1. Definition of artificial reefs

For the purposes of these guidelines, the following has been adopted as a standard definition to promote a common understanding of the term. This definition derives from the *Guidelines for the placement at sea of matter for purpose other than the mere disposal (construction of artificial reefs)* (UNEP-MAP, 2005), the *Guidelines for the Placement of Artificial Reefs* (London Convention and Protocol/UNEP, 2009), the *Assessment of construction or placement of artificial reefs* (OSPAR Commission, 2009), and the *Guidelines and management practices for artificial reef siting, use, construction, and anchoring in Southeast Florida* (Lindberg and Seaman, 2011).

An artificial reef is a submerged (or partly exposed to tides) structure deliberately placed on the seabed to mimic some functions of a natural reef, such as protecting, regenerating, concentrating and/or enhancing populations of living marine resources. This includes the protection and regeneration of habitats. It will serve as habitat that functions as part of the natural ecosystem while doing ‘no harm’.

The term excludes artificial islands, cables, pipelines, platforms, mooring, and structures for coastal defence (e.g. breakwaters, dikes, etc.) which are primarily constructed for other purposes, as well as the fish aggregation devices (FADs) employed to merely attract fish in certain fishing areas.

1.2. Objectives of artificial reefs

Artificial reefs can be considered as interventions of engineering technology to recover and/or improve natural habitats, increase productivity and manage aquatic resources.

In this context, artificial reefs are used in coastal waters worldwide for many purposes, e.g.:

- protecting sensitive habitats from fishing activities;
- restoring depleted habitats;
- mitigating habitat loss;
- enhancing biodiversity;
- improving populations of aquatic organisms by providing shelter for juvenile and mature individuals as well as for adults during delicate life stages (e.g. moulting season for crustaceans);
- providing new substrates for algae and mollusc culture;

- enhancing professional and recreational fisheries;
- creating suitable areas for diving;
- providing a mean to manage coastal activities and reduce conflicts;
- research and educational activities;
- creating potential networks of marine protected areas (MPAs) to manage the life cycles of fish and connectivity.

The objectives of artificial reefs deployment are not mutually exclusive as artificial reefs are often created for more than one purpose (e.g. protection from fishing and finfish enhancement). In this case, they are defined as "multipurpose artificial reefs".

1.3. Terminology

The use of a standard terminology for the different components of an artificial reef helps artificial reef developers to avoid confusion. In this document the following hierarchy based on that used for Japanese reefs (Grove *et al.*, 1991) has been adopted (Fig. 1):

- **Reef unit** or **module**: the smallest element constituting an artificial reef. The modules can be placed singly on the seabed or assembled.
- **Reef set**: structure formed by the assemblage of reef units.
- **Reef group**: area constituted by more modules and/or reef sets.
- **Reef complex**: formed by more than one reef group.

In this document the term "structure" refers to a module or a reef set.

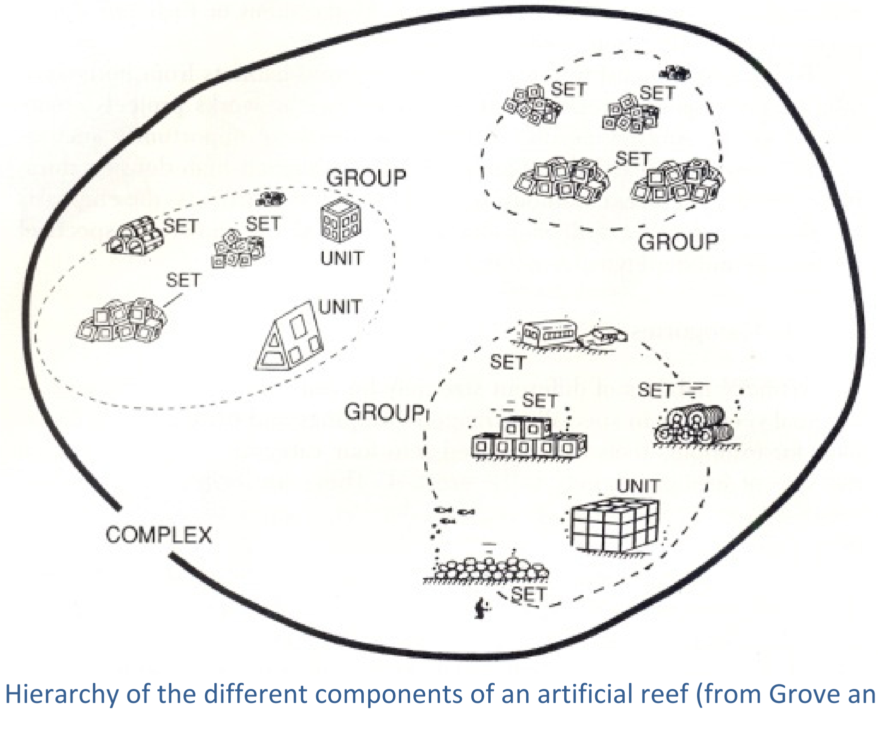


Figure 1. Hierarchy of the different components of an artificial reef (from Grove and Sonu, 1983).

2. International legislation on artificial reef deployment

Artificial reef deployment is an activity covered by several international legal instruments, including those on the protection of the sea against pollution due to the dumping of unsuitable materials. A list of these instruments is provided below in chronological order.

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter

The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (known as the "London Convention"), which entered into force in 1975, is one of the first worldwide conventions to protect the marine environment from human activities. In 1996, the Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the "London Convention Protocol") was adopted to update the London Convention by incorporating the principles of international environmental law laid down at the 1992 United Nations Conference on Environment and Development. In Art. 4 of this Protocol it is stated that contracting parties "shall prohibit the dumping of any wastes or other matter with the exception of those listed in Annex 1". These are:

- dredged material;
- sewage sludge;
- fish waste or material resulting from industrial processing operations;
- vessels and platforms or other man-made structures at sea;
- inert, inorganic geological material;
- organic material of natural origin;
- bulky items primarily comprising iron, steel, concrete and similar unharmful materials for which the concern is physical impact and limited to those circumstances, where such wastes are generated at locations having no practicable access to disposal options other than dumping.

The London Convention Protocol entered into force in 2006. In 2008, specific guidelines for the placement of artificial reefs were developed within the context of the London Convention and Protocol (London Convention and Protocol/UNEP, 2009). The Guidelines were approved by contracting parties to the London Convention and London Convention Protocol with the aim to, among others, assist countries in assessing proposals for the placement of artificial reefs on the basis of scientifically sound criteria. They are not legally binding.

United Nations Convention on the Law of the Sea

The 1982 United Nations Convention on the Law of the Sea (known as the "UNCLOS") is silent about artificial reefs. Although there are no specific provisions addressing artificial reefs in the UNCLOS, this convention stipulates the rights enjoyed by States over marine waters. This implies that, depending on the jurisdiction over given areas of the sea, States may deploy artificial reefs. This would be the case, in particular, of territorial waters where the coastal State enjoys sovereign rights.

Convention on the Protection of the Black Sea against Pollution

The 1992 Convention on the Protection of the Black Sea against Pollution (known as the "Bucharest Convention") was ratified by the six Black Sea riparian States and entered into force in 1994. Its overall aim is to protect the marine environment of the Black Sea and preserve its living marine resources. The Bucharest Convention has the following four Protocols:

- The Protocol on the Protection of the Marine Black Sea Environment against Pollution from Land Based Sources (also known as the "LBS Protocol") adopted in 1992 and in force since 1994, the revised Protocol on Protection of the Black Sea Marine Environment Against Pollution from Land Based Sources and Activities was adopted in 2009 and has not yet entered into force;
- The Protocol on Cooperation in Combating Pollution of the Black Sea Marine Environment by Oil and other Harmful Substances in Emergency Situations (also known as the "Emergency Response Protocol"), adopted in 1992 and in force since 1994;
- The Protocol on the Protection of the Black Sea Marine Environment Against Pollution by Dumping (also known as the "Dumping Protocol"), adopted in 1992 and in force since 1994;
- The Black Sea Biodiversity and Landscape Conservation Protocol to the Convention on the Protection of the Black Sea Against Pollution (also known as the "CBD Protocol"), adopted in 2002 and not yet entered into force.

Article 8 of the Dumping Protocol also applies to artificial reefs.

Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean

The 1995 Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (known as the "Barcelona Convention") replaced the 1975 United Nations Environment Programme Mediterranean Action Plan of the Barcelona Convention, a regional cooperative effort launched in 1975 involving the European Community and 21 countries bordering the Mediterranean Sea. The main objectives of the Barcelona Convention are:

- to assess and control marine pollution;
- to ensure sustainable management of natural marine and coastal resources;
- to integrate the environment in social and economic development;
- to protect the marine environment and coastal zones through prevention and reduction of pollution, and as far as possible, elimination of pollution, whether land or sea-based;
- to protect the natural and cultural heritage;
- to strengthen solidarity among Mediterranean coastal States;
- to contribute to the improvement of the quality of life.

The Barcelona Convention has been complemented by seven protocols which address specific aspects of Mediterranean environmental conservation. These protocols are known as:

- the Dumping Protocol (from ships and aircraft), adopted in Barcelona, Spain, on 16 February 1976, entered into force on 12 February 1978, revised in Barcelona on 9–10 June 1995;
- the Prevention and Emergency Protocol (pollution from ships and emergency situations), adopted in Barcelona, Spain, on 16 February 1976, entered into force on 12 February 1978;

- the Land-based Sources and Activities Protocol, adopted in Athens, Greece, on 17 May 1980, entered into force in June 1983, amended in Syracuse, Italy on 6–7 March 1996;
- the Specially Protected Areas and Biological Diversity Protocol, adopted in Geneva, Switzerland, on 2 April 1982, entered into force in 1986, revised in Barcelona, Spain, on 9–10 June 1995;
- the Offshore Protocol (pollution from exploration and exploitation), adopted in Madrid, Spain, on 13–14 October 1994;
- the Hazardous Wastes Protocol, adopted in Izmir, Turkey, on 30 September–1 October 1996;
- the Protocol on Integrated Coastal Zone Management (ICZM), adopted in Madrid, Spain, on 21 January 2008.

The following guidelines were also developed:

- Guidelines for the placement at sea of materials for purposes other than the mere disposal (construction of artificial reefs) (UNEP-MAP, 2005);
- Technical guidelines for the environmentally sound management of the full and partial dismantling of ships (Secretariat of the Basel Convention, 2003).

FAO Code of Conduct for Responsible Fisheries

The 1995 FAO Code of Conduct for Responsible Fisheries (known as the "Code of Conduct" or "CCRF") is a voluntary instrument that aims at underpinning sustainable fishing practices. To this end, when addressing fishing operations, it also contains provisions on artificial reefs and fish aggregation devices. As such, it is of specific relevance as it links these tools to fisheries-related uses. In providing guidance to States, the Code of Conduct states the following:

> "8.11.1 States, where appropriate, should develop policies for increasing stock populations and enhancing fishing opportunities through the use of artificial structures, placed with due regard to the safety of navigation, on or above the seabed or at the surface. Research into the use of such structures, including the impacts on living marine resources and the environment, should be promoted.
>
> 8.11.2 States should ensure that, when selecting the materials to be used in the creation of artificial reefs as well as when selecting the geographical location of such artificial reefs, the provisions of relevant international conventions concerning the environment and safety of navigation are observed.
>
> 8.11.3 States should, within the framework of coastal area management plans, establish management systems for artificial reefs and fish aggregation devices. Such management systems should require approval for the construction and deployment of such reefs and devices and should take into account the interests of fishers, including artisanal and subsistence fishers.
>
> 8.11.4 States should ensure that the authorities responsible for maintaining cartographic records and charts for the purpose of navigation, as well as relevant environmental authorities, are informed prior to the placement or removal of artificial reefs or fish aggregation devices."

3. Planning

Planning an artificial reef includes different phases: pre-construction, construction and post-construction. The first two phases are time-limited, while the last phase will continue over the entire lifetime of the reef.

A crucial factor of success is effective cooperation between numerous maritime stakeholders, including national, regional and local government authorities, managers, planners, engineering offices, fishers (artisanal, recreational and commercial), divers and all stakeholders concerned with the coastal management of their marine estate. When all interested parties are involved and kept informed about activities connected to the construction, management and use of the artificial reef and their status, through stakeholders' consultation and engagement, then these parties are more likely to offer guidance and assistance (see Chapter 9).

Therefore, it is important that a management plan clearly describing how the reef will be managed over its intended design life be developed by the proponent and adopted prior to the installation of the artificial reef. This management plan should illustrate the proposal, its goal and objectives, its pre-installation planning (including stakeholders' consultation and environmental assessment). Moreover, it should provide detailed information on the methods to be used to assess the effectiveness of the reef, the proposed mitigation measures to be implemented in the event of the reef causing a negative impact on the environment as well as the reef's target users or non-target stakeholders.

3.1. Pre-construction phase

This phase involves all actions to be undertaken prior to the installation of an artificial reef; from the decision to construct the reef to the submission of its plan to the competent authorities.

The first step in planning an artificial reef consists in identifying the broader goal(s) for its construction (e.g. to enhance recreational fisheries or manage professional fisheries) as well as evaluating the ecosystem where the artificial reef should be deployed and how that environment will be affected by the immersion of new substrates, not only during the immediate installation process but also over the reef's intended design life, which is likely to be around 30 years or more. Many questions relating to the "effect" of the artificial reef after its installation can be addressed thanks to the effective use of pre-installation environmental assessments which investigate the anticipated impacts (both positive and negative) of the installation of the reef and propose mitigation strategies for its ecological, physical and socio-economic impacts. These assessments can be used to formulate effective management plans for the reef's post-installation operation in the longer term.

Therefore, the questions to be asked and answered before making any commitment in terms of planning and development are the following:

a) Is the concept of the reef realistic? This question is aimed at evaluating if the construction of an artificial reef is valid and feasible in a particular area.

b) How will the new reef and the natural ecosystem interact? It is essential that the influence of an artificial reef upon the seafloor is understood before its construction, in terms of how the natural habitat may be modified and how ecological processes may be affected by the new substrates. This is particularly important for the long-term operation of the reef. Concurrently, it is necessary to evaluate the local, social and economic situation and to involve potential users of the artificial reef in order to consider their opinions on the project.

Once the above questions have been addressed, more specific objectives should be defined (e.g. increasing the income of the local fisheries up to a certain level).

When the broader goals and specific objectives of the artificial reef have been defined, it is necessary to calculate the investments as well as expected ecological and socio-economic returns. With clearly defined goals and objectives, it will be then possible to verify the performance of the artificial reef over time.

c) What are the potential alternatives to reefs construction which may produce similar environmental, social and economic outcomes? What would be the likely situation if the reef were not built (e.g. continued degradation of natural habitats due to illegal fishing activities)? Answering this question also helps evaluate whether the choice of constructing an artificial reef is actually more effective than other solutions.

Once the specific objectives have been established and a preliminary cost analysis has been performed, the reef site can definitively be identified and the artificial reef designed.

In selecting the reef's site, it is important to take into account: the physical features of the proposed site (water depth, sediment grain size and sediment cover, mean and extreme current, wave size and direction, etc.); the life history of the target species (i.e. distribution, reproduction, feeding, etc.), and the specific location of the site for the purposes of the reef (e.g. if an artificial reef is constructed to enhance local small-scale fisheries it should be located to provide cost-effective access from nearby mooring sites).

In addition, the choice of materials must comply with international and national legislations to avoid dumping and pollution in the marine environment. Moreover, the artificial reef should be designed by experts in the field, based on ecological and technical specifications relating to its purposes and setting. The structural integrity of the reef's units and of the subsequent groups to be created should be given equal weighting to anticipate their ecological effectiveness, as a reef that is unstable will ultimately fail to meet its ecological objectives.

Finally, the operational long-term management plan has to be submitted to the competent national and/or local authorities which are responsible for the maintenance and monitoring of the artificial reef in order to obtain their authorization.

3.2. Construction phase

This phase comprises all activities related to the construction of the artificial reefs' structures and their deployment at sea.

In general, attention should be paid in identifying the construction area and granting access to a suitable marine staging and load-out site where the reef material can be stored, moved and loaded onto the deployment infrastructure. This area should have easy access from both land and water to facilitate the transportation of the reef materials.

A safety perimeter should be established and signalled by buoys around the deployment site to avoid risks to leisure boats, divers, etc. during construction. The activity of transporting the reef material from the staging area to the deployment site may restrict manoeuvrability and thus represent a potential hazard to navigation. Consequently, it is prudent to notify the relevant marine authorities having jurisdictional authority over the reef installation site of the proposed operational timetable.

One of the main problems in the deployment of artificial reefs is to precisely place the structures in the pre-planned locations. It is therefore suggested to identify each site using a differential global positioning system (DGPS) and mark it with temporary marker buoys.

Once the deployment operations have been completed, the correct position and orientation of the reef structures (including minimum safe navigation depths on the lowest astrological tide [LAT]) should be verified through direct observation by scuba divers, surface deployed remote cameras or indirect surveys with side scan sonar or multibeam echosounder (MBES). The final location of the reef units (including the boundary of the reef complex) and the safe navigational depths (LAT) should be provided to national and regional hydrographers authorities so that they can be included in navigational map updates (e.g. notice to mariners).

3.3. Post-construction phase

After the artificial reef construction, the next question to be answered is: how can the reef be managed and used in a sustainable way? This question is aimed at identifying management options to optimize the reef’s benefits to all users and reduce conflicts among them. This aspect may not be particularly relevant when an artificial reef is constructed by private entities that have the ownership of the reef site. However, it is fundamental in the case of artificial reefs sponsored by national, regional or local authorities for the local communities (see Chapter 11).

Another important step is to determine the effectiveness of the artificial reef. A scientifically valid monitoring programme must be developed and “success criteria” established. Monitoring will enable the project sponsors to gain evidence concerning the ecological and socio-economic performance of the reef in relation to the expected objectives (see Chapter 9).

4. Siting, design and construction of artificial reefs

4.1. Site evaluation for artificial reef deployment

This chapter describes the environmental and socio-economic aspects to be taken into consideration when selecting a site for artificial reef construction.

From an environmental point of view, the proper location of an artificial reef is essential to optimize its ecological features and can strongly influence the effects expected from its establishment.

Physical and chemical variables as well as ecological features should be taken into account when identifying the location of an artificial reef. Physical and chemical variables include sediment type, depth/bathymetry, currents, waves, sedimentation rate, water turbidity, salinity and nutrients.

The stability of a reef is related to its structural characteristics (i.e. weight, density and modules design) as well as to the sediment type, current intensity, and wave motion. On muddy bottoms, strong currents and wave action can cause sediment movement leading to sinking and scouring, with consequences such as the destruction or displacement of the artificial structures. Waves and currents can also cause sliding, toppling and displacement due to excessive lateral forces, as well as the redistribution of sediments and mud on the horizontal surfaces of the substrates. This mud can be subsequently removed by current and wave action, with consequential loss of recently settled sessile organisms. Concomitantly, areas characterized by a strong sedimentation (such as the areas close to river mouths and coastal areas with limited water flow) should be avoided. These effects are more severe at shallower depth close to the shore.

Depth and turbidity affect the light penetration into the water, thus influencing the colonization of artificial substrates by algae and other photophylous organisms. This can affect in turn the fish assemblage that will inhabit the reef. Moreover, water temperature is often related to depth, as warm waters tend to stratify above the colder waters, creating a thermocline that can represent a barrier to some organisms.

Nutrient concentration can deeply affect the composition of the community settled on the substrates. In oligotrophic water with a low sedimentation rate, it is well known that the temporal evolution and the structure of the sessile community mainly depend on the gradient of light attenuation, hence on the depth. Hydrozoans, serpulids and bryozoans are usually the main pioneer organisms just after the immersion of artificial structures but, later, algae tend to become dominant. Mussels are usually absent while oysters may constitute a relevant component of the benthic assemblage. In eutrophic waters instead, light is less important. In this case too, pioneer organisms are represented by hydrozoans, serpulids and hydrozoans but, after a short time, the benthic community becomes largely dominated by filter-feeders such as mussels and interstitial organisms associated to them which find a suitable habitat in the mussel byssum (e.g. errant polychaetes and amphipods). The proximity of the deployment site to sources of pollution may lead to an accumulation of contaminants in the organisms inhabiting the artificial reef.

The biological variables to be used to determine the right position of an artificial reef are the following: habitats existing at the reef site and in the surroundings, life history of target species and connectivity.

In general, artificial reefs should not be deployed on rocky substrates, existing coral reefs or inside seagrass meadows, unless the reef is not designed to restore an existing damaged habitat. When an artificial reef is deployed close to hard-bottom habitats or other sensitive habitats, a buffer of sufficient size should be placed around the natural habitat to protect it from unintentional deviations from the planned deployment (Lindberg and Seaman, 2011). The typology of surrounding habitats can affect the benthic community and fish assemblage at the artificial reef in terms of recruitment, composition and abundance.

Usually, the proximity of seagrass meadows and natural reefs is associated with the recruitment rate at the artificial reef by fish and larvae of benthic organisms (Bombace *et al.,* 1994). On the contrary, the level of isolation of artificial reefs has been linked to top-down predator control of the community structure with a higher predation pressure on larger reefs or reefs close to natural reefs with respect to small isolated reefs (Shulman, 1985; Connell, 1998; Belmaker *et al.,* 2005). Hence, it is expected that the same structures will be colonized by different assemblages and at different rates when placed at various distances from similar habitats.

Moreover, it is important to take into account the life history, the role of some environmental physical and chemical parameters in the different life stages, migratory routes and linkages between adults and juveniles of the target species as well as known migratory routes of threatened and protected species (such as cetaceans), especially in the case of restoration and production artificial reefs.

Therefore, pre-deployment assessments should be conducted at the reef site to determine the sediment type, grain size and thickness (which may be used as an indicator of wave action and water movement); water depth; the occurrence, buffer and cover of natural hard substrates and/or seagrass meadow as well as any identified existing critical habitats adjacent to the proposed site; the intensity and direction of currents and waves (including maximum wave heights for extreme weather events such as 1/100 RI storm events). In addition, any valuable information on the biology and ecology of target species should be collected. This information will help refine the reef site selection and identify the most suitable materials and modules to ensure the stability and effectiveness of the reef over time.

Siting an artificial reef must also take into consideration the purposes of the project and the expected end users. Proximity to ports and other facilities is important if an artificial reef is constructed to enhance local artisanal fisheries, recreational fisheries or diving opportunities, as the reef might not be fully used if it is placed too far from safe harbours and mooring sites. On the contrary, if fisheries or diving enhancement are not one of the primary goals of the reef, its distance from land may not be relevant.

Depth and currents should also be considered when the goal of the artificial reef is to create new areas for diving, as high depth and strong currents might make the area not desirable and potentially dangerous for divers.

Finally, in order to avoid conflicts among users, placement decisions regarding artificial reefs should account for already existing or planned activities in the area. These activities include navigation, recreation, fishing, aquaculture as well as those related to MPAs. This consideration is particularly important in the case of large-scale artificial reefs. A useful tool in the initial selection of suitable reef sites is the use of constraints mapping. This is where all known barriers to reef construction are layered and mapped concurrently. These may include (but not be limited to) existing adjacent MPAs, natural reefs and other natural habitats such as seagrass meadows, known critical habitats, designated commercial fishing areas (such as trawl shots), cable exclusion zones, military exclusion zones, water depth and distance from safe harbour and moorings. This will ultimately narrow down the area that remains suitable and help better define and justify areas of greater interest which need further detailed investigation. In general, prior to artificial reef deployment, the different users of the area and potential stakeholders should be adequately informed through direct and indirect consultation about the reef project, and their viewpoints should be considered in the selection of the reef site.

4.2. Materials

The kind of materials used can affect the design life and longevity of the reef, the colonization of artificial substrates by benthic organisms and, consequently, the composition of the fish assemblage that will inhabit the reef.

First of all, the materials should be inert in order to avoid pollution and bioaccumulation of contaminants in the environment and in aquatic organisms.

The choice of the reef materials should also consider aspects such as resistance to the chemical and physical forces that are in constant action in the marine waters, lifetime and suitability for colonization by benthic communities.

With regard to stability, a general rule is that the weight of the materials used for the construction of the reef units should be at least double the specific gravity of seawater or, alternatively, that the structure should actually be anchored to the seabed (OSPAR Commission, 1999). In terms of durability, the materials should assure a minimum lifetime of 30 years. As for functionality, the materials have to be suitable to colonization by benthic organisms, based on field verification conducted for a minimum of one year. Lastly, for economic reasons, the materials should be cost-effective (Grove *et al.,* 1991).

Numerical modelling should be applied to verify that the reef will remain structurally intact and "on-station" over at least 30 years, including in case of exceptional marine and weather events.

A wide range of natural and man-made materials have been used in artificial reef construction. Natural materials include rocks, shells and wood, the latter being less durable over time due to the action of burrowing organisms. Rocks can be scattered on the seabed, deployed in chaotic piles or assembled inside frames that are made of steel, iron, plastic or wood. Concrete, iron, steel and plastic are the most often used artificial materials worldwide. Fiberglass, coal ash by-products, ceramic and ferro-cement have also been employed. These materials facilitate the pre-fabrication of specifically designed modules prior to water transport to the deployment site.

A number of ecological considerations should also be made as some materials can be selective towards benthic organisms. For example, a greater abundance of benthic species has been recorded on concrete and plywood compared to fiberglass or aluminium (Anderson and Underwood, 1994). Moreover, Bombace *et al.* (1997) have found a selective settlement of the burrowing bivalve, *Pholas dactylus,* on the horizontal surfaces of coal-ash blocks. A list of potential materials for artificial reef construction, including their advantages and disadvantages is reported in Table 1.

4.3. Types of reef structures

The type of structures employed for the construction of an artificial reef is a key element for its success both in terms of stability over time and achievement of the expected ecological results. Therefore, it is important to take into account both the engineering aspects and the scope of the artificial reef when planning the reef units and/or the reef sets.

Reef units can range from very simple modules (e.g. rocks or manmade cubes placed singly on the seabed) to sophisticated, intricately designed structures made of several different materials (e.g. steel and concrete, steel and fiberglass) designed to provide optimum surface area through three-dimensional complexity while manipulating water flow and creating upwelling. Simple reef units can be assembled in reef sets to increase the three-dimensional complexity of the reef, hence enhancing its potential in the recruitment of larvae of benthic organisms and fish species. For the same scope, different typologies of reef units and/or reef sets can be used to create an artificial reef.

Shape, height and weight of the reef units and reef sets are crucial for their stability and durability. It often happens that structures completely sink in muddy bottoms because they do not have a base adequate to support their weight. Complex modules may collapse due to the forces of currents and waves. Hence, the ratio of weight to surface area is crucial for the stability of the artificial reef units.

Nevertheless, structures of opportunity such as waste material are still largely employed. These structures include, for example, old ships, aircrafts, old vehicles such as cars, bus, train carriages, tracks, car tires, debris from demolition projects and parts of obsolete offshore platforms. Among the countries of the Mediterranean and the Black Sea, the use of these materials is strictly regulated by national laws according to the international conventions and protocols to avoid the dumping of waste at sea. It is important to underline the need to clean up these structures prior deployment in order to avoid the release of hydrocarbons, anti-fouling and heavy metal pollutants in the surrounding environment and the costs related to these operations (more specific information on the procedures to be followed are reported in UNEP MAP, 2005). In fact, from an economic viewpoint, although these “waste” materials may be initially cheaper to obtain (such as a “gifted” decommissioned naval vessel), the cost of preparation and clean-up prior to scuttling may be prohibitively expensive.

Lighter gauge metal, fiberglass and ferro-cement vessels tend to collapse. Moreover, fiberglass hulls have a low density and need to be appropriately weighted with denser materials to avoid movement to the sea surface. Car tires are highly unstable and may contribute to degradation of the marine environment. The sinking of car bodies causes both dispersion of harmful substances in the environment and disintegration of the metal parts with consequent loss of fouling organisms settled on them (Relini and Orsi Relini, 1971). It has been estimated that car bodies may have about three years of useful life as an artificial reef (Atlantic and Gulf States Marine Fisheries Commission, 2004).

Different technical project approaches are required when using modules specifically designed for artificial reefs and constructed with new or pristine materials. In the former, particular attention should be addressed to design and spatial arrangement of the structures, while in the latter, especially in the case of old ships and similar structures of opportunity, cleaning and siting the structures should be the primary issues to be taken into account. As a precautionary approach, structures of opportunity should not be placed close to sensitive natural habitats (Gobierno de España, Ministerio de Medio Ambiente, 2008).

4.4. Artificial reef dimensions

Artificial reef dimensions typically include measures to determine the surface area, total volume of material and bottom coverage (i.e. footprint). The reef bulk volume is the overall volume of the reef, which includes the structural volume and the interior volume. The structural volume is the volume of the material, while the interior volume is the space enclosed within the external envelop of the reef structures and the free space between them (Grove *et al.,* 1991). It stands to reason that reef footprint and volume (internal and structural) will all be bound to some degree to cost.

Also in this case, the optimal dimensions of an artificial reef strictly depend on its purposes. For example, the extension of protection and restoration artificial reefs is strictly linked to the area to be protected or restored. The former should be so extended to completely prevent the passage of fishing boats in the area to be safeguarded, while the latter should have a recovery potential proportional to the total surface of the habitat to be restored.

With regard to artificial reefs for stock and fishery enhancement, according to the Japanese experience, a reef set should have a minimum bulk volume of 400 m^3 while the optimal artificial reef size would be 3000 m^3/km^2 of bulk volume (Sato, 1985). Generally, small artificial reefs may not be able to sustain permanent populations of some species due to insufficient food availability. However, given an equal amount of immersed material, a higher density of fish is usually reported at smaller artificial reefs with respect to larger reefs because the former have higher perimeter and can attract fish from larger areas (Bohnsack *et al.,* 1991).

Table 1: List of materials for artificial reef construction: features, advantages disadvantages (modified from Atlantic and Gulf States Marine Fisheries Commissions, 2004)

Materials		Advantages	Disadvantages
Natural materials	**Wood**	– Availability. – Boring organisms increase habitat complexity providing space for other organisms and forage for invertebrates and fish.	– Short life span in the marine environment as it is broken down rapidly by boring and microbial organisms. – Due to light weight it must initially be ballasted to be kept in the site. – Processed wood, used for many construction purposes, is often treated and can contain toxic compounds.
	Shell	– Shell reefs present little hazard to navigation if planted at a low profile and, therefore, can be used in shallow waters without the cost of permanent buoys. – Compatible with the marine environment.	– Shells must generally be purchased. – Shell is a small material and, consequently, has a tendency to be silted especially if the substrate is sandy or muddy.
	Rock	– Compatible with the marine environment. – Quarry rock is a very stable and durable material. – It is a good fish attractant and provides a good surface for fouling organisms. – Different size particles of rock can be used to accommodate different life stages of species of interest.	– Quarry rock must be purchased. – Transportation costs to both the staging and reef sites is expensive and the use of heavy equipment is required. – Potential subsidence into the sea bottom.
Artificial materials	**Concrete**	– Extremely compatible with the marine environment. – Possibility of developing prefabricated units. – It provides excellent surfaces and habitat for the settlement and growing of encrusting organisms which provide forage and refuge for invertebrates and fish.	– Due to its heavy weight, heavy equipment is required for its handling, it can greatly increase the cost of transport and installation. – Potential subsidence into the sea bottom. – The ability to recycle this material is currently reducing the availability of concrete for use as artificial reef construction in some areas.
	Steel	– Possibility of developing large prefabricated units of very high relief and unmatched complexity. – If sand blasted, provides excellent surfaces and habitat for the settlement and growing of encrusting organisms which provide forage and refuge for invertebrates and fish.	– Reduced design life in shallow or highly oxygenated water bodies (i.e. rough exposed coastlines). – High relief of large singular modules may cause stability issues requiring increased anchoring considerations of units resulting in increased reef costs.

Artificial materials	**Fiberglass**	– Fiberglass reinforced plastic is strong, nontoxic and does not corrode in sea water. – It can be used to construct all components of an artificial reef structure so that the entire structure has the same durability. – Its great strength allows to construct large artificial reef structures using very little material. – It is suitable for the settlement of benthic organisms and for attracting fish.	– Due to lightweight, fiberglass reef structures are unstable in open water marine environments. Therefore, they must be properly ballasted in order to assure that they do not move in response to currents or storm wave forces. – Fiberglass is a relatively expensive material.
	Ash	– Possibility to realize modules of various shapes and dimensions. – The European Protection Agency (EPA) determined that all large volume coal combustion wastes generated at electric utility and independent power producing facilities are exempt from hazardous waste.	– Testing of fly ash for toxic components is expensive and may be cost prohibitive to artificial reef programmes.
	Electrodeposition	– The materials used to build a reef with electrodeposition would weigh substantially less than most other reef materials (e.g. concrete) and would presumably cut down on transportation costs. – Electrodeposited reefs can be repaired *in situ* if they are damaged, this would not be possible with most modular reef materials. – Its versatility enables you to create underwater structures of any size and shape.	– Because of its mostly experimental use, it is unknown how stable the reefs would be under adverse sea conditions or what its longevity would be as a viable artificial reef. – The need for an electrical source requires a platform to be at the reef site and the electrical equipment must be checked frequently.
	Recycled inert materials	– Research and development of new products from recycled materials (not limited to demolition waste) allows a wide choice. – The use of recycled materials can reduce the costs for artificial reef construction.	– In all cases it is intended to use recycled materials, their inert nature must be verified, and it is often not feasible. – Some recycled materials, while being inert, have proved to be inadequate for fixing sessile organisms (e.g. tires, some plastics). – Possible high cost of packaging and decontamination.

Artificial materials	**Vehicle tires**	– Vehicle tires are lightweight and easy to handle, particularly when unballasted. – Vehicle tires may be readily available in large quantities. – Vehicle tires may be acquired free or at low costs. – Tires will last indefinitely in the marine environment; this might be considered a benefit in the context of the material being durable. – Tires used as artificial reefs can be effective in attracting fish.	– Tire recycling alternatives are available. Large scale deployment of tires at sea as a waste disposal activity under the umbrella of artificial reef construction is no longer viewed by management and regulatory agencies as environmentally acceptable. – If used, tires should be clean and free of petroleum or other environmentally incompatible substances prior to deployment. – Due to lightweight, unballasted tires are unstable in open water marine environments. Therefore, they must be properly ballasted to assure that tire units do not move in response to currents or storm wave forces. – Properly ballasted tire units are more expensive, bulky, heavy, and difficult to handle and to transport without heavy equipment. This may not make tires as cost-effective as other materials that can accomplish the same objective. – Tires must be stable for fouling or epiphytic communities to attach to them. – Single tires lay flat on the sea bottom and provide little or no habitat value for fish. – Assuming that tires will last indefinitely in the marine environment, tire units will last only as long as the connectors or binding material holding them together remain intact (even when ballasted, multiple tire units that use steel reinforcement rods as a connector will separate after several years due to corrosion of the rods). Each tire used in multiple tire units must be ballasted. Once multiple tire units come apart, the remaining single tires will provide little or no habitat value. – Tires will last indefinitely in the marine environment. This is considered a drawback in the context of tires being unstable in salt water.

Artificial materials	**Vessels**	– Vessels make interesting diving locations for divers. Vessels are also regularly used as angling sites by recreational fishers and the charter fishing industry. – Vessels used as artificial reefs can, alone or in conjunction with other types of artificial structures, generate reef-related economic contributions to coastal communities. – Due to their high vertical profile, vessels can attract both pelagic and demersal fish, produce upwelling conditions, current shadows, and other current speed and direction alterations that are attractive to schooling forage fishes, which in turn attract species of commercial and recreational importance. – Vessels may provide shelter and spawning habitat for reef fish. – Vessels may provide extensive surface area for epibenthic colonization. – Sinking a vessel often creates a media event, providing artificial reef managers with promotional opportunities for their reef programmes.	– Providing accessibility to both diving and fishing groups while still maintaining adequate navigational clearance above vessels often limits placement of vessels (particularly large ships) within a relatively narrow depth range (24 to 36 m). – Good water clarity is preferred to enhance diver observations, and this may further limit vessel placement. – Vessel stability may be variable, especially during major storms. Susceptibility or resistance to movement depends upon a combination of factors such as depth, extent of vessel surface area exposed to wave energy, vessel orientation with respect to storm direction, wave height, vertical profile, etc. Vessels placed in shallow depths (less than 50 m) are more susceptible to movement during major storm events. – Vessels can be contaminated with pollutants, including: polychlorinated biphenyls (PCBs), radioactive control dials, petroleum products, lead, mercury, zinc and asbestos. Hazardous wastes and other pollutants are difficult and expensive to remove from ships. Other materials, not necessarily classified as hazardous wastes, but which may pose environmental or safety problems such as floatable materials (wood, styrofoam) and plastics, may be required to be removed (tire bumpers, white goods, toilets, etc.). – The removal of hazardous materials, pollutants, and other materials not authorized for artificial reef disposal under the permit requires additional expense, time and, in some cases, special equipment and expertise. The cost to safely place a vessel in the ocean as an artificial reef increases as the size of the vessel, the number of compartments, void spaces and overall complexity increase. – Vessels typically provide proportionately less shelter for demersal fishes and invertebrates than other materials of comparable total volume. This is because the large hull and deck surfaces provide few, if any, holes and crevices. – Unless a vessel hull is extensively modified to allow for access, water circulation and light penetration, most of the interior of the vessel is not used by marine fishes and macroinvertebrates. – Vessels are at greater risk of sinking off site while under tow, either to the salvage site or the permitted area itself, than other artificial reef materials carried on or in more seaworthy vessels. – Salvage efforts may weaken the structural integrity of a vessel or result in significant reduction in its vertical profile and complexity, due to loss of the superstructure. – Vessels have an alternate value as recyclable steel.

Artificial materials	**Steel-hulled vessels**	– More resistant compared to fiberglass and wooden vessels. – No need of being ballasted to maintain their position on the seafloor.	– The surface of a steel hull is a less ideal surface for colonization by epibenthos than rocks or concrete. Sloughing of steel, due to corrosion, results in loss of epibenthic animals and increases contamination of the environment.
	Fiberglass vessels	– Discarded fiberglass boats are readily available and cheap.	– The fiberglass vessels have to be cleaned and sufficiently ballasted for sinking. – This material may have little long-term value as reef habitat due to instability, lack of durability or lack of proper preparation.
	Wooden vessels	– Boring organisms increase habitat complexity providing space for other organisms and forage for invertebrates and fish.	– Wooden vessels, especially smaller ones, have both stability and durability problems. They are subjected to the action of boring and microbial organisms and may break up in storm situations when placed in shallow waters or if not properly ballasted. Floating debris presents a hazard to navigation or may wash ashore as unsightly beach litter. Increasing water depth for deployment does not appear to improve the longevity of wooden vessels. – A best-case scenario is that the wooden parts disintegrate after one to five years, leaving the heavy ribs and keel and the associated metal components (engines, boilers, metal masts, etc.) to serve as fish and diver attractants, thus providing some short-term economic benefits to some individuals. – Processed wood, used for many construction purposes, is often treated and can contain toxic compounds.
	Vehicles	– Vehicle bodies are readily available, inexpensive, and are relatively easy to handle, not requiring heavy equipment to move.	– Vehicle bodies require a great deal of preparation and removal of contaminant material prior to being ready for deployment. This activity can be labour intensive. – Vehicle bodies are not durable, they last for one up to five years in the marine environment. Considering that about one year is necessary to establish an encrusting or fouling community, along with a relatively stable population of fish, and considering that significant deterioration has likely begun to take place after four years, vehicle bodies may have about three years of useful life as an artificial reef. – Vehicle bodies are not stable, and are likely to be moved easily by storm surge or a boat pulling a trawl, resulting in the material being moved from its original location. – Fiberglass, rubber and plastics attached to automobile bodies, if not removed when deployed, may become unattached and free in the water column after the metal corrodes away. – Recycling of the steel may be a more economically beneficial use of vehicle bodies than allowing them to corrode within a few years on the ocean floor.

4.5. Placement of the artificial structures

The disposal of reef units and/or reef sets inside an artificial reef group or complex needs to be planned on the basis of a range of criteria depending on the purposes of the artificial reef.

In the case of artificial reefs constructed as a fishing deterrent, the type of vessels to be deterred and the fishing gear used have to be taken into account when calculating the distance between the reef structures and their spatial disposition.

In artificial reefs deployed for fisheries enhancement, the spatial disposal of the reef units and/or reef sets should be planned on the basis of their individual area of influence towards the different fish species targeted, in order to optimize the reef effects on them.

More detailed information on the spatial disposal of the reef units and reef sets are given in Chapter 5.

4.6. Time of deployment

The time of deployment may influence the time of development and the structure of the benthic community that will colonize the artificial substrates, favouring the settlement of some organisms rather than others. For example, in tropical regions it can be beneficial to deploy the artificial reefs at certain times to prevent them from algal overgrowth and increase survival of coral recruits. In temperate regions, larval settlement of most species occurs in late spring-summer, hence it might be advantageous to deploy the artificial substrates in those seasons or just before. Additionally, the timing of deployment may have serious economic implications for the reef installation costs as standby rates incurred by large marine infrastructures can easily double the installation costs. Therefore, prevailing seasonal weather conditions should be considered when planning reef deployment strategies.

5. Function-specific criteria

This chapter provides more detailed information on the criteria to be used in the construction of artificial reefs according to their purpose. Five categories of artificial reefs are considered: 1) protection artificial reefs; 2) production artificial reefs; 3) recreational artificial reefs; 4) restoration artificial reefs and 5) multi-purpose artificial reefs.

5.1. Protection artificial reefs

5.1.1. Objectives

The main purpose of this type of artificial reefs is to act as a dissuasion tool for fisheries (i.e. illegal trawling) and as a protection tool for marine resources, environment and other legitimate activities.

This application is frequently used to protect habitats of ecological interest or of importance for some life stages of some resources (e.g. *Posidonia* beds, maerl beds, coralligenous, biogenic reefs, reproduction and nursery areas, sensitive and essential fish habitats, etc.) from illegal trawling, dredging and bottom purse-seining that can damage both the habitat and its associated resources. The use of appropriately-designed artificial reefs may help control and reduce conflict between trawling and coastal small-scale fisheries using set gear.

Some protection artificial reefs can be used to protect other structures like cables, oil or waste water pipelines thereby preventing pollution damage.

5.1.2. Design and material

Protection artificial reefs should be specifically designed to withstand the power of fishing vessels in an area and to either hook nets or tear them up. Therefore, the units must be heavy enough to steadily maintain their position on the seabed and avoid removal by fishing vessels. Several artificial reefs have failed because the modules were shifted or hauled up by the fishing vessels. Consequently, protection units should be dense and relatively low profile, with a low volume in relation to their weight. The weight should be related to the power of the fishing vessels to be stopped. Concrete blocks with deterrent arms are usually employed (Fig. 2).

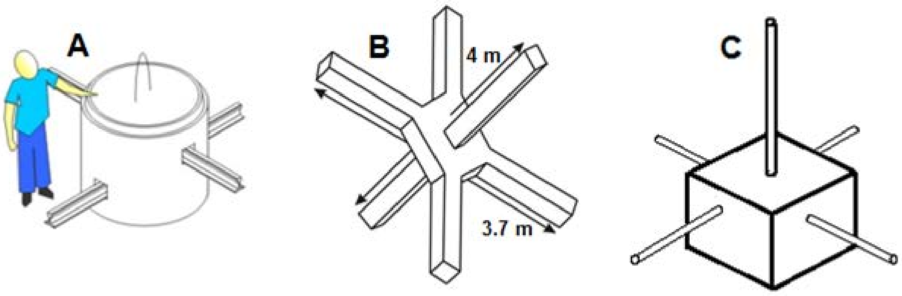
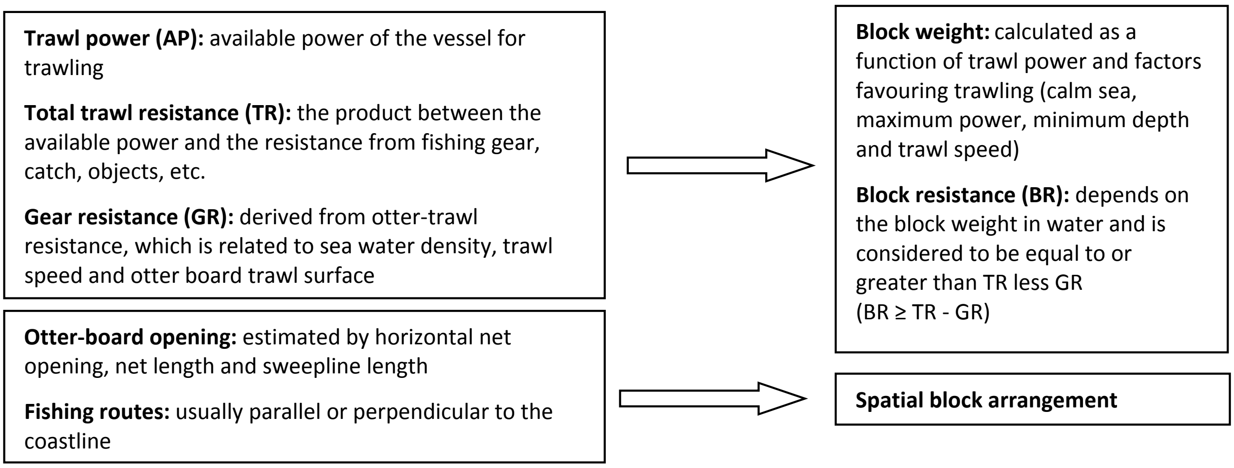


Figure 2. Examples of protection units: A) Spain; B) France; C) Tunisia (modified from J.J. Goutayer Garcia, E. Charbonnel and N. Haddad).

Figure 3 shows the technical parameters to be considered in designing protection artificial reef units. A good review of the technical characteristics for the design of protection artificial reef units is provided in Ramos-Esplá *et al*. (2000).



Trawl power (AP): available power of the vessel for trawling

Total trawl resistance (TR): the product between the available power and the resistance from fishing gear, catch, objects, etc.

Gear resistance (GR): derived from otter-trawl resistance, which is related to sea water density, trawl speed and otter board trawl surface

Block weight: calculated as a function of trawl power and factors favouring trawling (calm sea, maximum power, minimum depth and trawl speed)

Block resistance (BR): depends on the block weight in water and is considered to be equal to or greater than TR less GR (BR ≥ TR - GR)

Otter-board opening: estimated by horizontal net opening, net length and sweepline length

Fishing routes: usually parallel or perpendicular to the coastline

Spatial block arrangement

Figure 3. Variables to be considered when designing anti-trawling reef units (modified from Ramos-Esplá *et al.,* 2000).

5.1.3. Siting

Considering the extended area typically covered by protection artificial reefs, planning the location of the units on the seabed requires detailed knowledge of several features of the seafloor such as the distribution of natural habitats and the position of man-made structures (pipeline, cables, etc.) in order to protect them, avoid damages and prevent negative impacts.

It is also essential to know the fishing routes in the area in order to strategically place modules along designated lines perpendicular to the routes. The distance between modules should be less than the otter-board/dredge openings, hence than the free space needed by the vessel to pass with the towed gear between one module and the other, taking into account the best relationship between the artificial reef's effectiveness and costs. Usually, these modules are placed alternate along two or three parallel lines.

When protection artificial reefs are deployed to create suitable grounds for selective small-scale fisheries and to protect the resources from other less selective fishing activities, the reef units should be placed following a spatial design which allows for the use of set gear within the reef area.

Several protection artificial reefs have failed in their protection function because the units were haphazardly dropped from the sea surface and, hence, became scattered on the seabed without following a specific design. Therefore, the use of GPS combined with controlled release of the modules by crane can assure their correct positioning and effectiveness.

5.1.4. Practical applications

Several examples of this application exist in the Mediterranean Sea (e.g. Spain, Tunisia).

- Spain

The development of artificial reefs in Spain is motivated by the need to protect coastal fishing resources, high-diversity biological communities and selective small-scale fisheries against the action of non-selective fishing methods like trawl and seines.

More than 130 artificial reefs have been constructed along the Spanish coasts since 1989, most of them for protection purposes, as a tool for Spanish fisheries policies. Along the Mediterranean coast, the depth of deployment ranges from 10 to 35 m – sometimes up to 50 m. The projects developed in Spain for protection artificial reefs have tried to optimize the design of units to improve their function and optimize both the number of units and their arrangement on the seafloor (Fig. 4). The goal was to protect as much area as possible minimizing costs and habitat modifications. Cost reduction was also achieved using maritime conventional means to install the reefs without the intervention of divers.

The results indicate an increase of local fishing resources, a reduction of conflicts between fishers and, in some cases, a significant recovery of natural habitats.

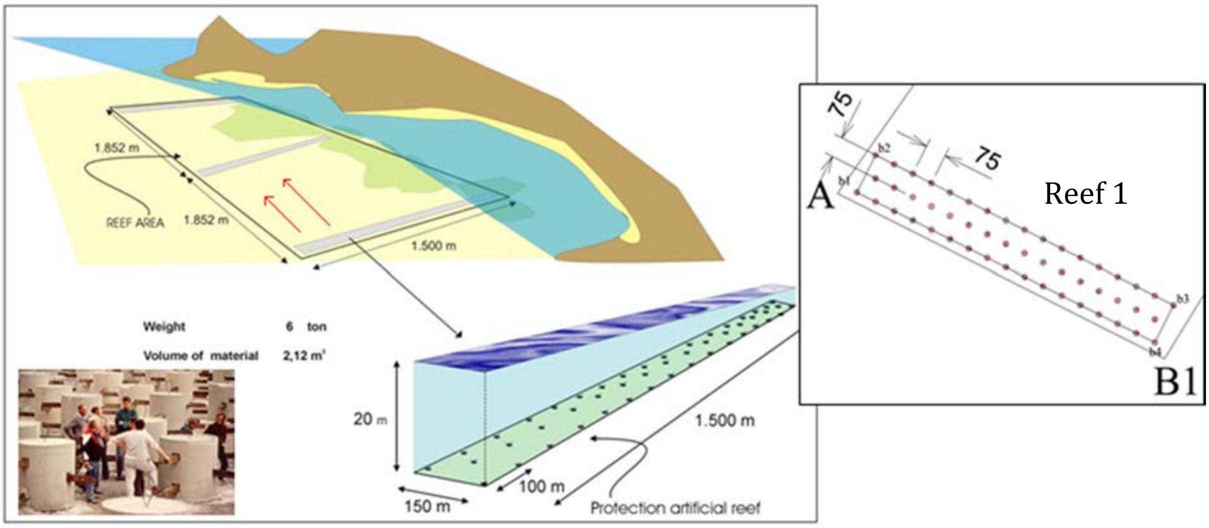


Figure 4. Scheme of a protection artificial reef (Spain). The protection units are placed along three lines perpendicular to trawlers navigations routes (red arrows) to protect the *Posidonia* and *Cymodocea* beds (green area) inshore and leave space for artisanal fishing activities (modified from J.J. Goutayer Garcia).

5.2. Production artificial reefs

5.2.1. Objectives

The overall objective of production artificial reefs is to increase the productivity of the aquatic environment and promote a sustainable utilization of resources.

When opportunely designed, artificial reefs may increase the biomass and hence the availability for human consumption of a variety of aquatic organisms (algae, molluscs, sea-urchins, fish) by enhancing their survival, growth and reproduction providing them with suitable habitats and additional food.

This type of artificial reef can also be used to manage the life stages of targeted species favouring aggregation of juveniles in certain areas and gathering the adults at suitable fishing grounds.

The specific applications of production artificial reefs include:

- recovery of depleted stocks by increasing juveniles survival providing them with shelter and additional food;
- enhancement of local fisheries by aggregating and establishing permanent populations of fish at suitable fishing grounds;
- shifting the fishing effort from an overexploited resource to other resources; e.g. if the soft-bottom associated species in an area are overexploited, artificial reefs can serve to shift a part of the fishing effort to pelagic or reef-dwelling species;
- compensation for a reduction of fishing effort: when there is a need to reduce fishing effort of trawling in an area, production artificial reefs can be used in negotiation to create new fishing grounds allowing fishers to shift towards more selective fishing activities;
- development of extensive algae and molluscs aquaculture, providing suitable substrates for settlement.

5.2.2. Design and materials

The modules that are generally used for production artificial reefs should be alveolar, of various shapes, and their surface area and niches (of various shapes and sizes) should be appropriate for the establishment of settling organisms. Unlike protection reef units, production units have usually more volume in relation to their weight, hence creating the three-dimensional complexity and developing surfaces which can be colonised by sessile organisms (Fig. 5). Rough surface texture enhances benthic settlement as it provides refuge and supports a greater diversity (Harlin and Lindbergh, 1977; Hixon and Brostoff, 1985; Beserra Azevedo *et al.*, 2006). Consequently, this also affects the fish assemblage attracting fish grazing.

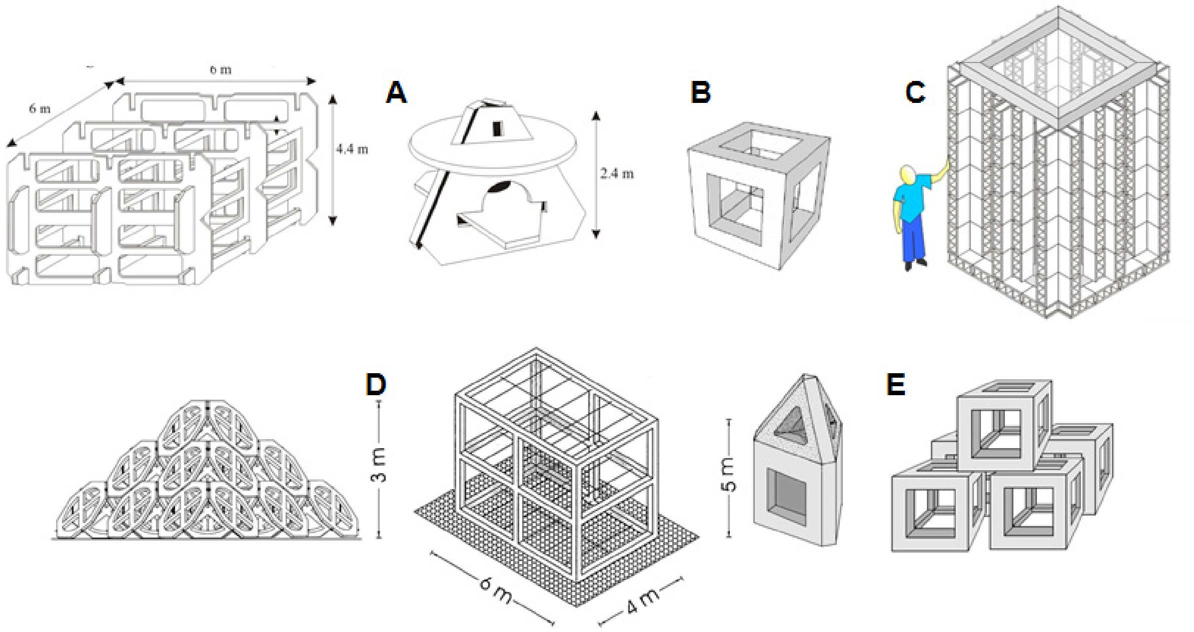


Figure 5. Examples of production artificial reef modules: A) France; B) Tunisia; C) Spain; D) Italy; E) Turkey (modified from E. Charbonnel, N. Haddad, J.J. Goutayer Garcia, CNR-ISMAR Ancona and A. Lök).

Food availability in the production artificial reef, as well as the composition, diversity and abundance of reef fish are strongly influenced by the occurrence of adequate refuges and by the shape of the structures. Habitat quality affects habitat selection by fish and, consequently, influences demography and population dynamics of the reef fish assemblage. Hence, to host a permanent community, an artificial reef must provide adequate habitats to juveniles and adults. On the basis of the fractal crevices theory in structurally complex natural or artificial environments, large crevices are much rarer than the smaller ones. Therefore, the artificial reefs can host a greater number of small and medium-sized organisms than large ones which tend to migrate outside. Therefore, the placement of large-holed reef units (especially in MPAs) could avoid depletion of broodstock by fishing and enhance the reproductive capacity of reef fish (Caddy, 2011).

Other factors that should be taken into account in planning artificial reef structures are:

- Regardless of their size and life stage, fish generally prefer cavities where there is light and with many openings that enable them escaping from predators;
- the size, number and orientation of cavities should match with the behavioural features of the target species, such as whether they are territorial or gregarious;
- the overall design of artificial reef structures should assure adequate water circulation;
- if demersal species are targeted, the structures design should consider providing vertical cover such as an “overhang” or shading from above as demersal fish will more readily utilize structures which provide protection from predators foraging from above.

With regard to the shape of the reef units/reef sets, it is well known that the affinity of several aquatic organisms towards the artificial substrates vary widely depending on the species and the life stage. Because of this, when constructing a reef for fisheries enhancement, it is important to deeply know the ecology of the different species so to identify those that are more appropriate as targets for artificial reef deployment and will have a higher probability of being manageable through manipulations involving artificial reefs.

Fish species have been classified according to their affinity to artificial reefs (Nakamura, 1985; Grove *et al.,* 1991; Bortone, 2011; Fig. 6):

- **Type A**: benthic, reef-dweller organisms (fish, crustaceans, cephalopods) that prefer to live at strict contact with the substrates or inside holes (e.g. gobids, blennids, scorpenids, octopus and lobsters);
- **Type B**: nekto-benthic, reef-dweller fish that swim around the structures but are linked to them by the occurrence of shelter and/or prey availability (e.g. sparids, sciaenids, seabass and labrids);
- **Type C**: pelagic fish swimming in the middle and surface layers of the water column; they usually maintain a certain distance from the artificial structures but are likely to be linked to them by vision and sounds (e.g. mugilids, amberjacks and dolphin fish);
- **Type D**: species that are found on, in, or over the substrate next to the reef. These species have similar needs to C-type species but they live on or above the substrate surrounding the reef (e.g. bothids).

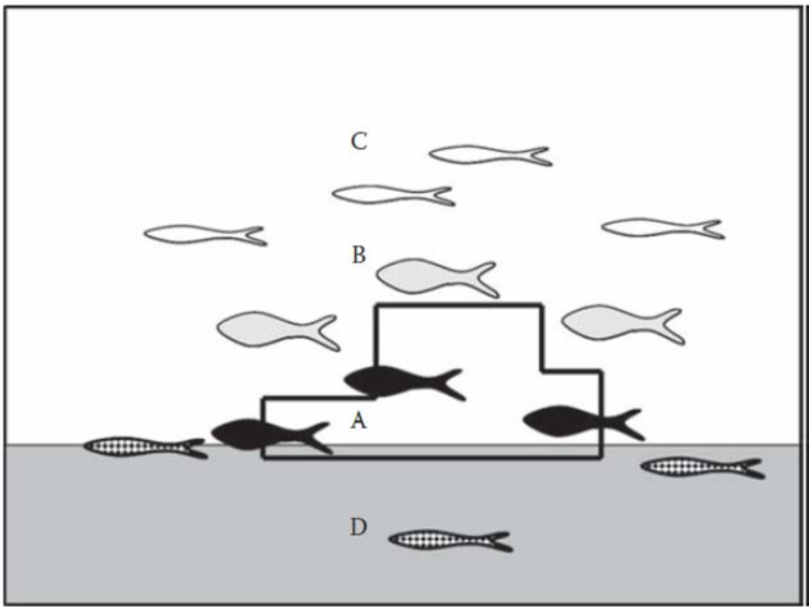


Figure 6. Classification of fish according to their position relative to the artificial reef (from Bortone, 2011).

In Figure 7, the different fish categories are displayed along two axes (attraction and production) according to their level of affinity towards hard substrates. C and D-type species are characterized by high attraction and low production relationships with artificial substrates, hence they are clearly not suitable to be managed with an artificial reef in terms of increasing production as these species are chiefly attracted to the reef. A-type species, which have a strong production relationship (e.g. spiny lobster or octopus) might gain a significant advantage from artificial reef deployment, while B-type fish will get benefit from artificial reefs depending on their life history strategies.

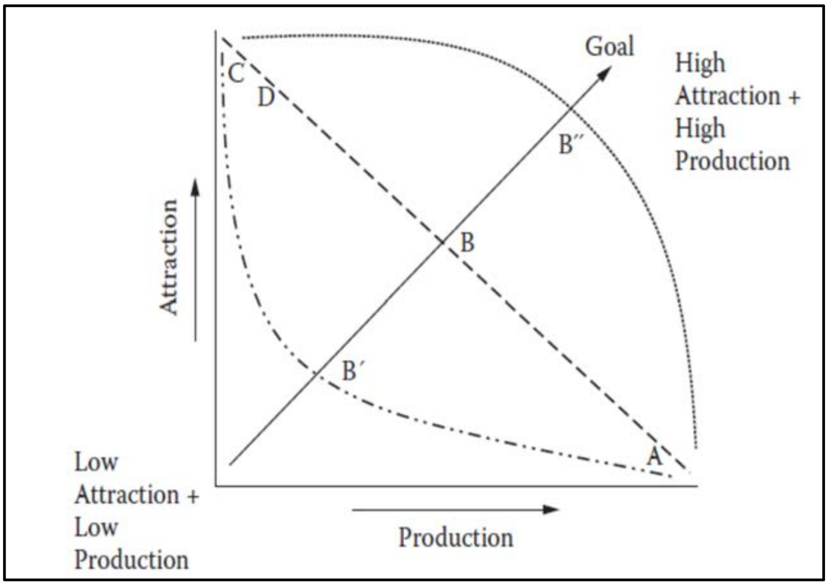


Figure 7. Relationship of A, B, C and D-type artificial reef species relative to attraction and production features of artificial reefs. B′ and B″ indicate the position of B-type species with different life history strategies (from Bortone, 2011).

To attract A-type organisms, the artificial reef structures do not need to extend vertically into the water column but should be provided with internal spaces matching with the size of the target species, while for B-type fish species the holes should be larger and the artificial reef structures must reach at least a height of 2 m. To aggregate C-type species, the artificial reef should extend vertically into the water column and its structures should have wide open spaces to favour the water flow. Simple units can be also used for particular species, e.g. clay jars for octopus. Consequently, the complexity and diversity of the fish assemblage associated to an artificial reef strictly depends on the complexity of the reef.

5.2.3. Siting

The displacement of reef structures within an artificial reef may affect its influence on fish. Greater distance between the reef units/reef sets may increase the total volume of the artificial reef but account should be taken of the fact that the effects on fish may be reduced if the units are placed too far from each other. The reef groups may act as isolated reefs (in space) if spaced too far apart. Correct spacing of reef units (or modules), reef sets and reef groups will ensure that the reef complex operates as one reef with fish readily transiting between refuge/predation points, which can greatly improve the “productive” value of the overall reef complex itself. The area of influence (or halo) of each unit, set and group will vary depending on target species and module design.

In general, the criterion to be applied in positioning artificial reef structures within a reef group is that the areas of influence of individual reef units and/or reef sets should overlap with each other (Grove *et al*., 1991). The reef groups do not need to interact with each other when included within a reef complex (Fig. 8).

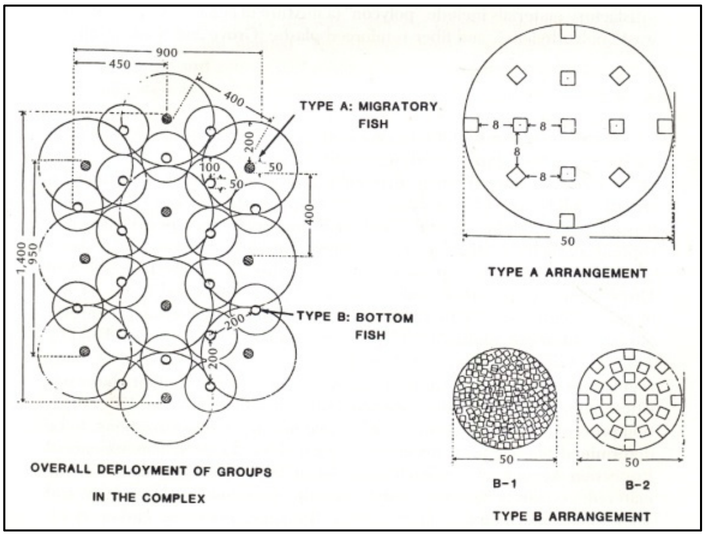


Figure 8. Spatial arrangement of reef units/reef sets in a reef complex (from Grove and Sonu, 1985).

Production artificial reefs should be placed in areas where stocks of target species already exist. Moreover, the reefs should match with the ecological requirement of those species. Usually in the Mediterranean Sea, this type of artificial reefs is placed in coastal waters up to 30 m depth, but the range depth can be appreciably greater in other seas (e.g. off Japan) where high relief artificial reefs are placed up to 80 m depth.

In the case of production artificial reefs aimed at enhancing and managing local fisheries, shifting the fishing effort helps compensate for the loss of fishing grounds due to other human activities. The choice should be towards B-type species which are attracted to reefs to a limited degree but also gain some production benefit from reef platform. With respect to the above-mentioned criteria, to assure stability and ecological effects, the artificial reefs should be placed as close as possible to the fishing harbours, hence allowing equitable and economic access by reducing travel and search times, saving on fuel and increasing fishers' safety.

Artificial reefs may also help localize and manage the entire life cycle of some target fish. In this case, different reefs – each matching with the ecological requirements of a certain life stage of the species – should be deployed along the movement routes to gather the specimens in localized areas.

5.2.4. Practical applications

- France

Among the 94 000 m^3 of artificial reefs existing in France, one third concerns the Marseille reef complex, which is the largest artificial reef deployed in the Mediterranean Sea with 27 300 m^3 covering 220 ha and conceived by marine biologists (Charbonnel *et al.,* 2011). The reef deployment relied on the creation of horizontal and vertical discontinuities in heights, sizes and volumes thanks to a great variety of reef types and shapes, as well as on diverse arrangements and horizontal spacing of reef units/reef sets. Six types of modules of different shapes, sizes, volumes and materials were specially designed for this project (Fig. 9). To optimize the reef habitat diversity, the complexity of these modules was enhanced adding several types of small filling materials (bags containing oyster shells, breeze blocks, octopus pots used for fisheries) and floating immersed ropes. Piles of quarry blocks of variable sizes were also used to reconstitute natural rocky boulders.

The different modules were grouped in six triangular shaped reef groups (300 m). These groups were linked together by series of reef structures (functional connections) functioning as biological corridors and stepping stones for fish and propagules. The locations of peripheral natural habitats (*Posidonia* meadows and rocks) were taken into account in the arrangement of the reef groups to favour a rapid colonization of the artificial reef (Fig. 9).

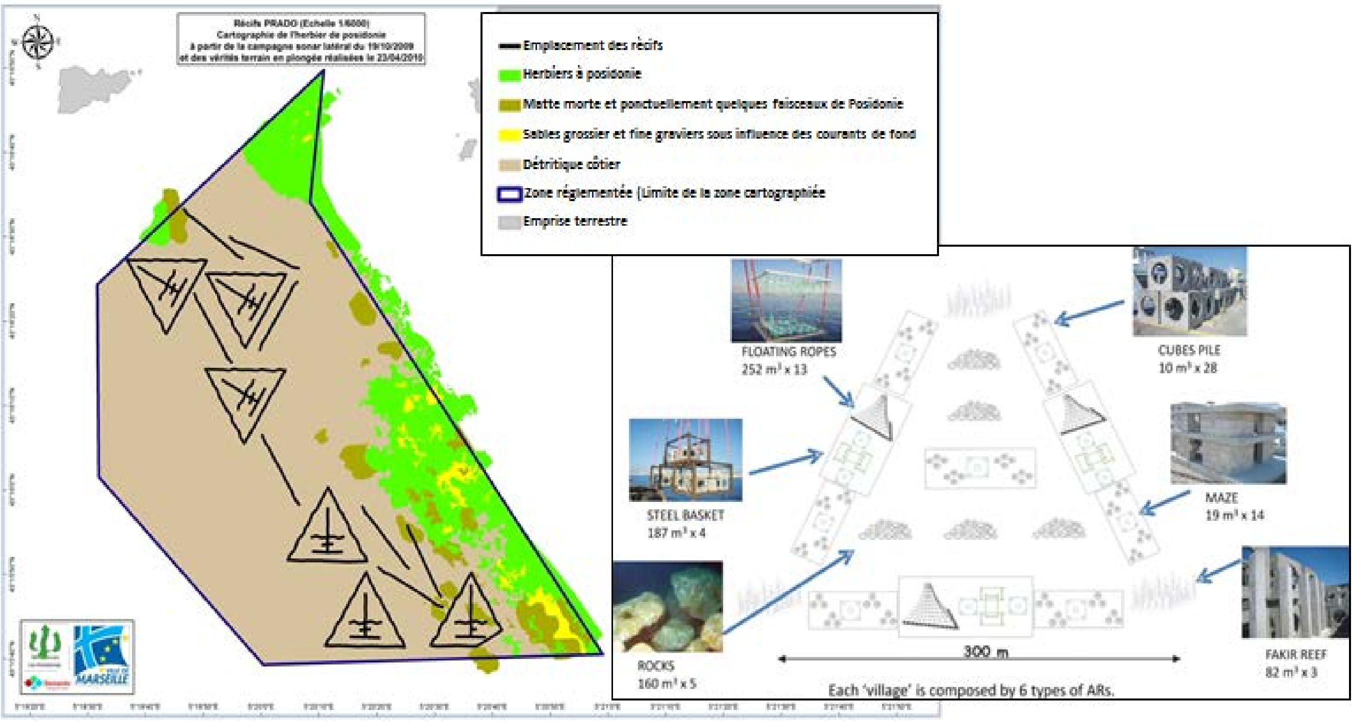


Figure 9. Marseille Prado artificial reef, France, the largest reef in the Mediterranean. Deployed in 2007–2008, it is composed of six "villages" linked by eight connections (above in green: lower limit of *Posidonia* meadow). Each village has a triangular shape and is made with six types of artificial reefs (below) (from Charbonnel *et al*., 2011).

- Greece

Four multipurpose artificial reefs were constructed in 2000–2006 for the protection and management of marine resources. The reefs have a surface area of 8–10 km^2 each and are made of different concrete modules. These are either mixed modules consisting of concrete cubic blocks with holes, deployed one by one on the seabed or assembled in pyramids, or production modules such as bulky cement-bricks on a concrete base and concrete pipes assembled in pyramids (Fig. 10).

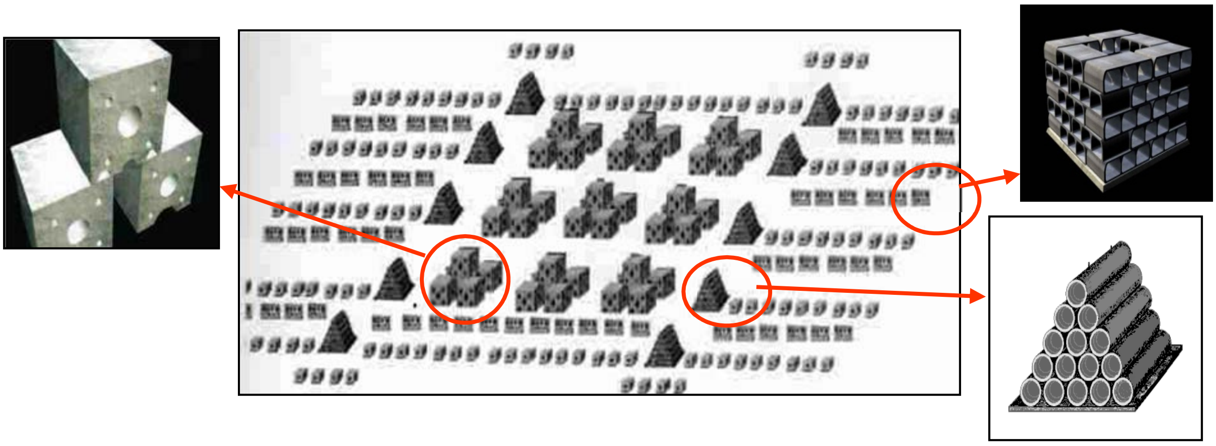


Figure 10. An artificial reef plan using four different types of modules in order to increase the reef complexity, Greece (modified from A. Kallianotis).

Turkey

Octopus species are habitat-dependent and of great economic interest. Despite a lack of specific information, data show that the individual weight of octopus has decreased over the last few years both globally and in Turkish seas. Furthermore, natural shelters of *Octopus vulgaris* along the Aegean coast of Turkey are often disturbed by spearfishers. For these reasons, a plan was created to deploy an artificial reef specifically designed for this species (octo-reefs). The goal was to provide octopus individuals with suitable habitats and to increase their population in the long term. Simple concrete modules with holes were placed on the sea bottom. The first results showed that octo-reefs were actually used by octopus (Fig. 11 and Plates 1 and 2). Hence, the next step will be to deploy this type of artificial reefs in a closed fishing area and in MPAs.

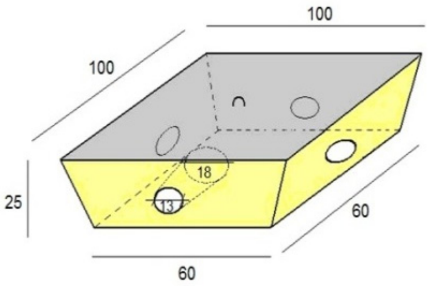
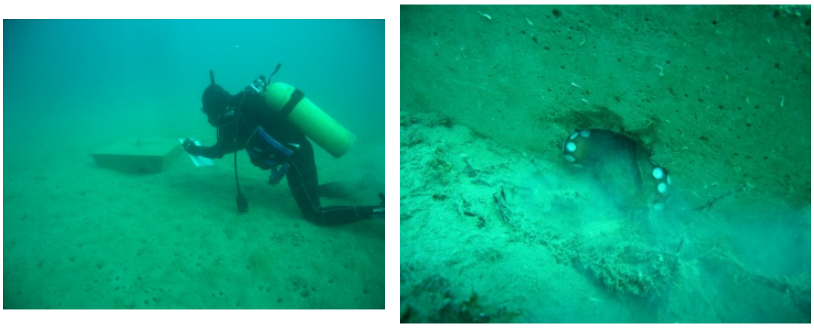


Figure 11. Production artificial reef units for octopus, Turkey (courtesy of A. Lök).



Plates 1 and 2. Production artificial reef units for octopus, Turkey (courtesy of A. Lök).

- Japan

Artificial reefs aimed at managing the life cycle of migratory fish were constructed in a bay of the Iki Islands (Sea of Japan), where schools of snapper (*Sparidae*) were observed to follow a migratory route coinciding with the propagation of waves inside the bay. The strategy adopted was to place a production artificial reef at the entrance of the bay, a spawning reef where the waves converged, and a nursery reef to improve the survival of juveniles (Fig. 12). This confined the life cycle of snapper into the bay, which considerably improved their survival, and allowed their catches to be managed by the local fishing communities (Nakamura, 1985).

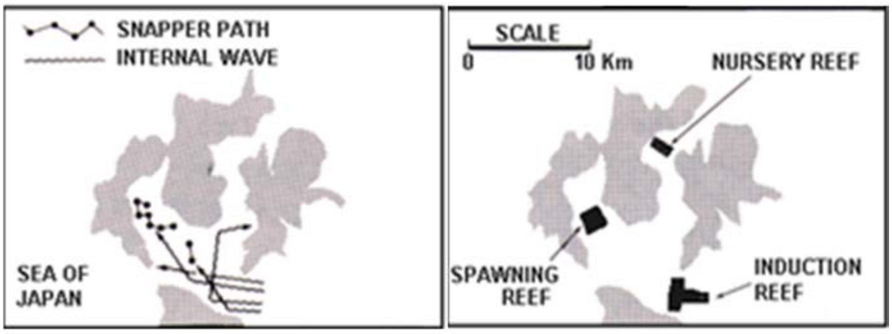


Figure 12. Deployment of artificial reefs aimed at managing the entire life cycle of snapper (from Nakamura, 1985).

Similar applications could be adopted in the Mediterranean and the Black Sea to manage the life cycle of some commercially important species, the juveniles of which, for example, prefer low depth and migrate towards offshore as they grow. A restocking experiment conducted with juveniles seabass (*Dicentrarchus labrax*; 15 cm TL) released in an artificial reef located at 11 m depth in the northern Adriatic Sea demonstrated that, just after release, the fish migrated inshore, close to estuarine areas. In the following months, during its growth, the fish migrated again to the artificial reef and the mussel cultures located between 10 and 13 m depth. In this case, the placement of suitable artificial reefs between the coast and the 13 m bathymetry could partially confine released seabass (Grati *et al.,* 2011).

5.3. Recreational artificial reefs

5.3.1. Objectives

These artificial reefs are constructed to create adequate zones for recreational fishing and diving.

The main purposes of these artificial reefs are:

- to attract tourists in areas where natural rocky habitats are lacking;
- to reduce the human pressure on natural, sensitive habitats;
- to reduce conflicts between professional and recreational fisheries in coastal zones.

5.3.2. Design and materials

There is a tendency to deploy shipwrecks to accommodate the needs of users (divers and recreational fishers). However, using vessels as diver attractants has some associated level of risk that should be carefully evaluated when choosing the vessel. High structure complexity and facility of penetration inside the wreck may increase the risk for divers. Moreover, it is important that the vessels are deployed correctly, in vertical position, and in such a way that their stability on the seabed is ensured. To create an artificial reef site that presents an ecological interest and is able to sustain recreational activities without using a vessel, the same approach should be applied as for production artificial reefs.

5.3.3. Siting

Recreational artificial reefs should be placed in areas that are easily accessible from the local harbours and/or from the beach, possibly in a sheltered position so that diving and recreational fishing are also possible in poor weather conditions. Variables such as water temperature, sea state, current velocity, depth, visibility, and distance from shore should all be taken into consideration since they affect diving conditions.

5.3.4. Practical applications

In the Mediterranean Sea, applications of this type of artificial reefs can be found in Albania, Cyprus, Israel, Malta and Turkey.

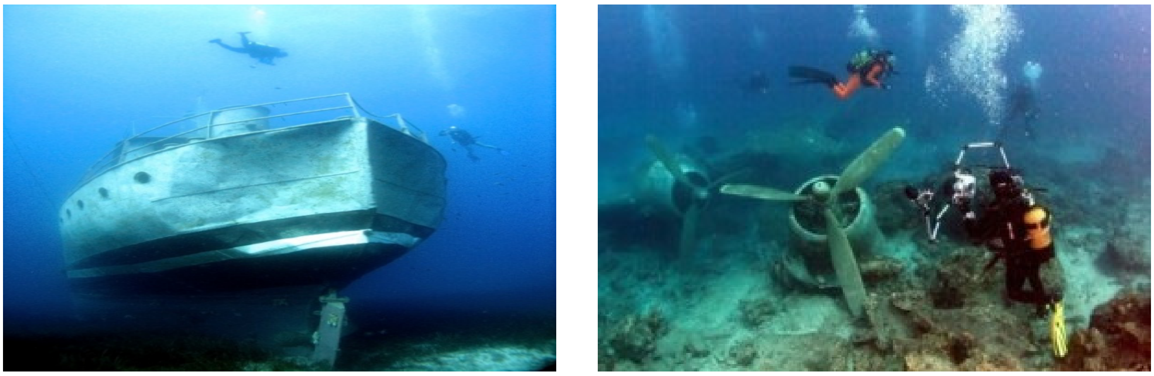
- Albania

The southern Albanian coastline hosts diverse and valuable marine habitats, which are threatened by rapidly increasing coastal development and tourism. A diving survey conducted in the last decade revealed that there was great potential for diving tourism in the Karaburuni peninsula. To protect the natural habitats from excessive pressure and improve the variety of diving opportunities, the immersion of a number of ex-naval vessels was forecasted within the Pilot Fishery Development Project (Government of Albania & World Bank, 2006). Five decommissioned Albanian Navy vessels were purposely sunk in 2010 in the Ksamil Bay with the support of the United States Navy ship Grapple (Plates 3 and 4).

Plates 3 and 4. Ship wrecks sunk as artificial reefs for diving in Ksamil Bay, Albania (courtesy of the Albanian Center for Marine Research and of TravelBlog, respectively).

Turkey

The Bodrum peninsula (southern Aegean Sea) is one of the most important touristic and recreational diving areas in Turkey. It has more than 25 diving schools and attracts approximately 200 000 divers each year. Every diver usually dives twice to natural habitats in a daily diving trip. After the immersion, in 2007, of two old ships and one aircraft (Plates 5 and 6) as artificial reefs in the south of Karaada (south of the Bodrum peninsula), half of the 400 000 dives moved to these wrecks. Therefore, half of the diving pressure and stress on natural habitats were removed through artificial reef application.



Plates 5 and 6. A ship wreck and an aircraft sunked as artificial reefs in the South of Karaada, Turkey (courtesy of A. Lök).

5.4. Restoration artificial reefs

5.4.1. Objectives

This kind of artificial reefs can be used to:

- recover degraded habitats and ecosystems where the interventions aimed to reduce the human pressure causing the degradation have failed;
- compensate the loss of ecologically important habitats caused by some human activities linked, for example, to coastal development and energy production (wind mills, offshore platforms, etc.).

In this case, the basic principle should be that of not creating something that would not naturally exist in the environment.

Particular attention is required in the use of artificial reefs for the rehabilitation of natural coral reefs. In this case, artificial reefs may represent a solution for coral reefs of particular economic value that were damaged by shipping accidents, or for damaged sites used by tourist operators. However, the use of artificial reefs is only recommended to supplement damaged reef areas of a few square meters. Such methods are not considered viable or feasible for coral reef rehabilitation over several square kilometres due to the potential damage that installation operations could cause to adjacent coral reefs and associated ecosystems (ICRI, 2009). Mitigation reefs should be created as soon as possible once damage on habitat or resources has been observed, as delays can contribute to increase ecological losses.

5.4.2. Design

In this case, natural materials that are as similar as possible to the original ones (boulders, stones, etc.) should be employed. In coral reef rehabilitation, boulders or concrete modules are usually employed and often associated with the transplantation of corals from the impacted areas to enhance the mitigation process.

5.4.3. Practical applications

▪ Denmark

An example of restoration artificial reef comes from Denmark, where natural cavernous boulder reefs have been extensively exploited for their high concentration of easy-to-excavate large boulders which makes them suitable for constructing sea defences and harbour jetties. In 2008, the Danish Forest and Nature Agency constructed the Laeso Trindel artificial reef (Kattegat) to restore and maintain the local cavernous boulder reef habitat, a site of importance designated as a Natura 2000 site in accordance with the European Union Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora). The project consisted in the immersion of around 60 000 m^3 of boulders of various sizes and weights (1–6 tonnes; Plates 7, 8 and 9).

Plates 7, 8 and 9. Laeso Trindel artificial reef: construction of the reef (left) and benthic colonization on the reef boulders (from Dahl *et al.*, 2009).

5.5. Multipurpose artificial reefs

5.5.1. Objective

To maximise the benefits from the construction of an artificial reef and reduce the costs, the reef is often planned to achieve more than one purpose. In this case it is called “multipurpose artificial reef”.

However, not all the functions of artificial reefs described above are compatible with each other. For example, in Australia there has been evidence that recreational line fishing and diving (primarily scuba diving) on artificial reefs were in direct conflict with each other and created some resource allocation issues. This has also been the case for intersector conflicts between spearfishers and line fishers. The most common application of multipurpose artificial reefs in the Mediterranean Sea combines the protection and production functions.

5.5.2. Design

A multipurpose artificial reef should include modules of different types or, alternatively, adequately designed reef units/reef sets. For example, an artificial reef for protection and production purposes could include both units acting as deterrents to illegal fishing and structures (units and/or sets) aimed to increase the biomass in the area. Alternatively, it can be constructed with modules/sets that perform both the functions (Fig. 13). In this case, mixed units are basically composed of protection modules with some characteristics of production such as small cavities or surfaces for the settlement of benthic organisms or eggs. Similarly, a production and recreational artificial reef can include both structures to increase the biomass and shipwrecks.

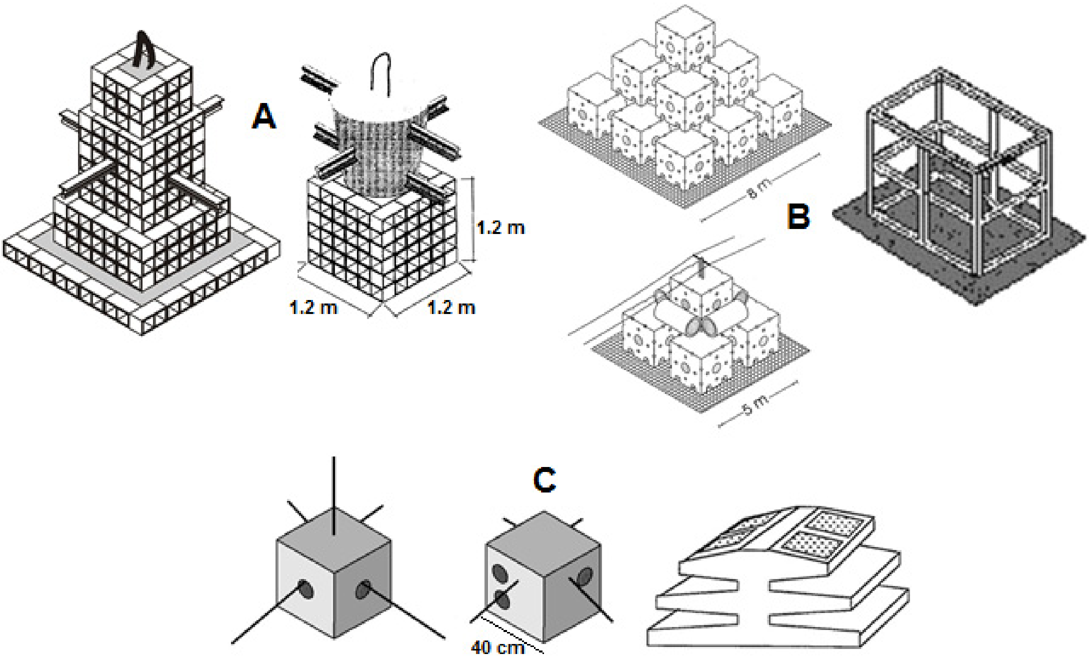


Figure 13. Examples of multipurpose artificial modules: A) Spain; B) Italy; C) Tunisia (modified from J.J. Goutayer-Garcia, CNR-ISMAR Ancona and N. Haddad).

5.5.3. Siting

The arrangement of the structures inside a multipurpose artificial reef depends on the purposes of the reef. For protection and production reefs, the protection units should be placed along the perimeter of the reef area and the production structures in the centre. The same should apply to artificial reefs created for protection, production and recreational purposes.

5.5.4. Practical applications

The most common examples of multipurpose artificial reefs are found in Italy, Greece, Spain and Tunisia.

- Protection and production

Italy – Since the 1970s, artificial reefs have been deployed along the Italian coastal waters to protect coastal habitats and fishing communities against illegal trawling and to enhance small-scale fisheries. Along the Adriatic Sea, where there is an important clam fishery (*Chamelea gallina*) operating with hydraulic dredges on sandy-mud bottoms located in shallow water up to about 11 m depth, small-scale fisheries are often in conflict with both illegal trawling – due to competition over the resources and the damage made to set gear – and hydraulic dredges – due to competition over space and damage to the gear. The strategy adopted to reduce these conflicts was to allocate space and resources to the construction of large-scale multipurpose (anti-trawling and production) artificial reefs at around 5.5 km offshore. The deployed modules can be gathered into three main groups: a) protection modules, b) production modules and c) mixed modules.

Anti-trawling structures associated with production units or mixed modules (Fig. 17) were used (Bombace *et al.,* 2000; Fabi, 2006; Fabi *et al.,* 2006). As trawlers are used to begin their hauls outside the 5.5 km zone and to penetrate the prohibited area perpendicularly to the shoreline, these reefs consist of rectangular zones, as long as possible, which are placed horizontally with respect to the coast. The distance between the modules was calculated on the basis of otter-board openings (Fig. 14). These artificial reefs contributed to reduce conflicts between fishers as they created a suitable area where small-scale fishers could carry out their seasonal activities according to the eco-ethology of the different species inhabiting the reef, often gathering in cooperatives to manage the reef areas and their resources.

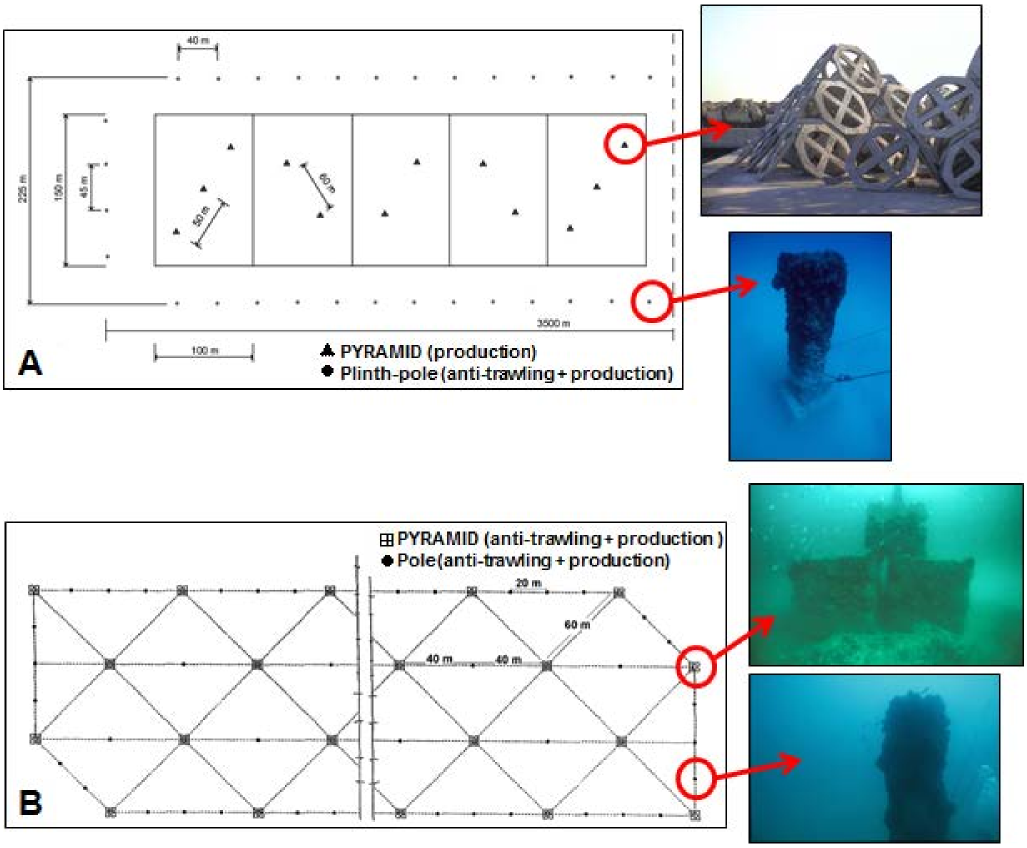


Figure 14. Examples of multipurpose artificial reefs deployed along the northern and central Adriatic coast, Italy (courtesy of CNR-ISMAR Ancona).

Spain – Similar strategies have been adopted along the Spanish Mediterranean coasts since the late 1980s with the aim of creating suitable grounds for selective small-scale fisheries and protecting them from other less selective fishing activities (trawling and seines), hence improving marine communities and preventing conflicts between fisheries. In this case too, protection, production and mixed modules were used and displaced to prevent trawling, regardless of the fishing vessels route (Fig. 15) (Moreno, 2000; Ramos-Esplá *et al.*, 2000).

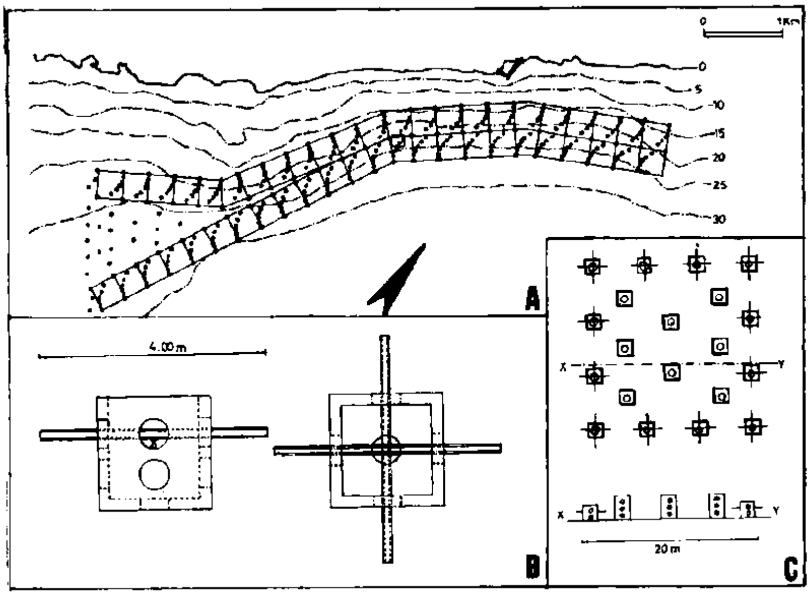


Figure 15. Example of a protection and production artificial reef (El Campello, Spain) realised with anti-trawling and mixed modules: A) plan of the artificial reef; B) protection unit; C) attraction/concentration set and displacement of the units inside a reef set (from Ramos-Esplá *et al.,* 2000).

Tunisia – In Tunisia there has been an increase in overfishing due to the introduction of large trawlers and a progressive decline of *Posidonia* meadows caused by the illegal activities of small-sized trawlers in coastal areas. Over the past ten years, these factors have led to a gradual decrease of demersal resources with a consequent reduction of the income of small-scale fishers. Moreover, it has been estimated that around 90 percent of seagrass beds, which represent important spawning and nursery areas for several coastal fishing resources, have disappeared in the Gulf of Gabès. To solve these problems, the Tunisian Government adopted in 2002 a management policy towards regulating fishing practices in order to maintain the balance between fishing pressure and exploitable fishing resources. The programme also included the adoption of active measures to protect and restore marine habitats on fishing grounds, enhance fishing resources and diversify small-scale activities. One of the most relevant management measures was the construction of protection and production artificial reefs. Most artificial reefs consisted of simple concrete blocks with iron bars to stop illegal trawling and, in some cases, with internal holes or bricks to give shelter to marine organisms. These reef modules were directly constructed by fishers. More recently, a new design has been adopted, which has allowed the construction of more complex multipurpose artificial reefs (protection and production). These new artificial reefs (Fig. 16) include modules for the production of algae, which also have a protection function (M1); production modules of different dimensions (M2 and M3); protection modules (M4) and modules for reproduction and nursery purposes (M5).

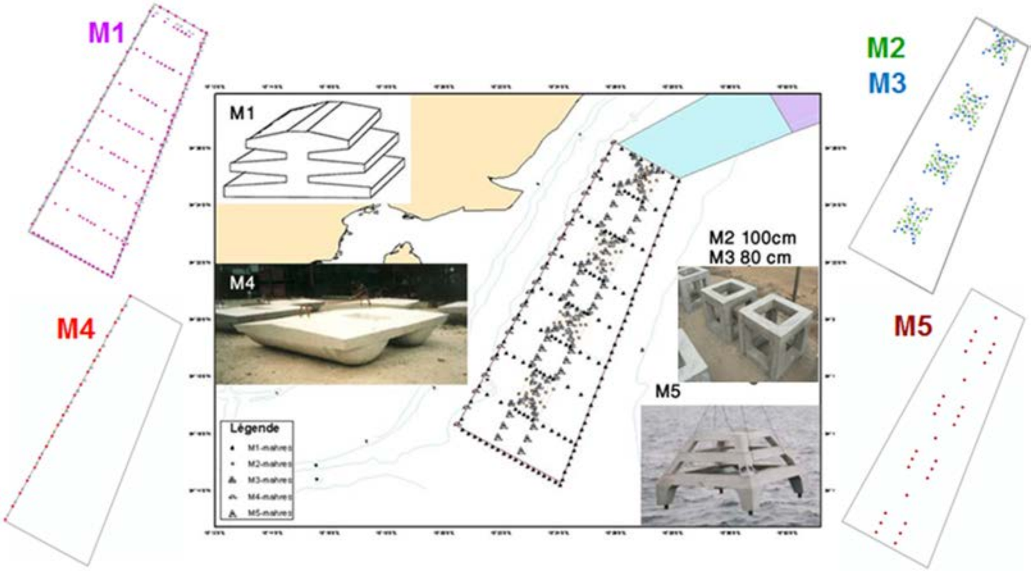


Figure 16. Plan of the multipurpose artificial reef Mahrés 3 (Gulf of Gabès, Tunisia) (modified from N. Haddad).

- Protection, production and extensive aquaculture

Italy – Artificial reefs have been deployed within the coastal area of the northern Adriatic Sea by local small-scale fishers associations in order to optimize their activity by creating suitable habitats for reef-dwelling fish and macroinvertebrates, and favouring the development of wild mussel populations. In this case, the reef sets were composed of two types of mixed modules: A) production and aquaculture; B) protection and production (Fig. 17).

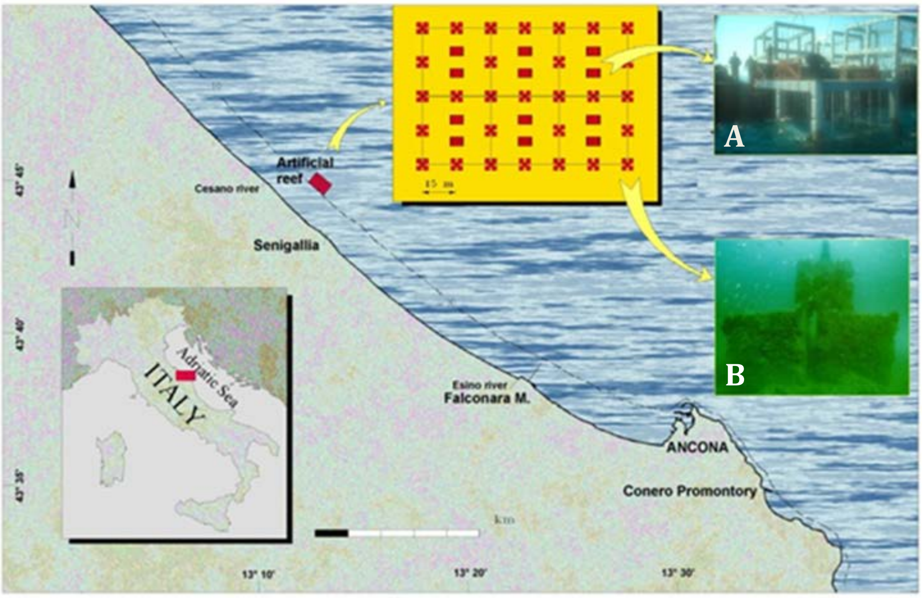


Figure 17. Example of multipurpose artificial reef (protection, production and extensive aquaculture), Italy. A) production and extensive aquaculture reef sets; B) protection and production reef set (courtesy of CNR-ISMAR Ancona).

These artificial reefs were usually placed close to the coast and in shallow waters (approximately 10 m depth) to facilitate mussel harvesting by professional scuba divers.

- Protection, production artificial reefs and MPAs

Artificial reefs can also be associated with MPAs.

France – From 1983 to 2004, 4 884 m^3 of production and protection artificial structures (2 684 m^3 and 2 200 m^3 respectively) have been deployed in the Côte bleue marine park (Fig. 18). Part of these man-made structures were placed within and around two no-take zones that are marine reserves of 295 ha where all kinds of fishing activities, scuba diving and mooring are prohibited. In this case, the establishment of the MPA and the deployment of artificial reefs were used as complementary tools which contributed to preserve traditional small-scale fisheries allowing all local fishers (around 60) to fish in the area, including after the establishment of the MPA. Conversely, these fishing activities have been decreasing in the nearby zones (Charbonnel and Bachet, 2011).

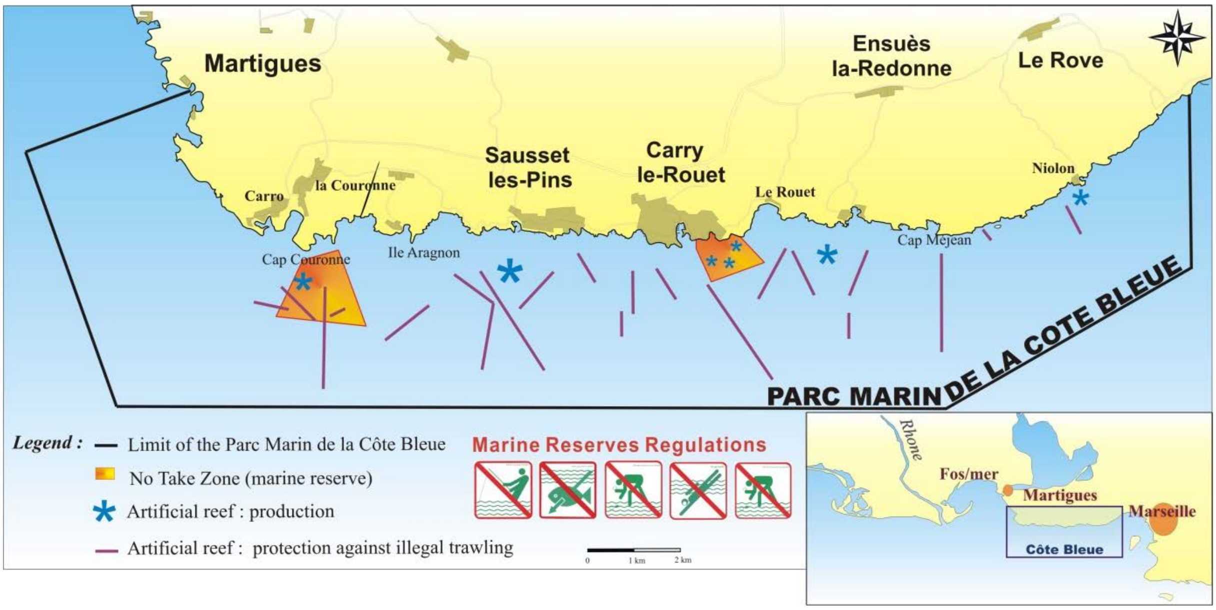


Figure 18. Multipurpose artificial reefs associated with MPAs. Case of the Côte bleue marine Park, France (from Charbonnel and Bachet, 2011).

6. Possible negative impacts

Artificial reef deployment may have negative impacts on the environment, either during the construction or once the reef has been established. These potential negative impacts should be considered in reef planning.

During the installation of an artificial reef, the presence of work vessels and other mechanical equipment can lead to the release in the environment of pollutants that might accumulate in the sediments. Moreover, the immersion of artificial substrates may induce a short-term increase of turbidity due to sediment disturbance, hence temporarily altering photosynthesis of algae, seagrasses and corals. Sediments suspended during the construction can also settle in surrounding habitats, where they may smother existing communities. The extent of the impacts will depend on the volume of the sediments disturbed and on local currents.

Once an artificial reef has been deployed, there may be some long-term environmental changes. These may be a modification of bottom currents leading to subsequent variations in the grain size distribution and possible localized sediment scour close to reef modules (Fig. 19). An additional effect may be a change in sediment organic content due to the metabolic activity of benthic and fish assemblages associated to the reef. These effects are likely to modify the original soft-bottom community inhabiting the surroundings. Such modifications can be either positive or negative. For example, a production artificial reef deployed on a seabed habitat that is degraded by organic polluted sediments can induce the development of a new, more productive, biological community. On the other hand, if the same artificial units are placed on *Posidonia* or maerl beds, the new benthic communities associated to the artificial reef can cause negative impacts on the original sensitive habitats.

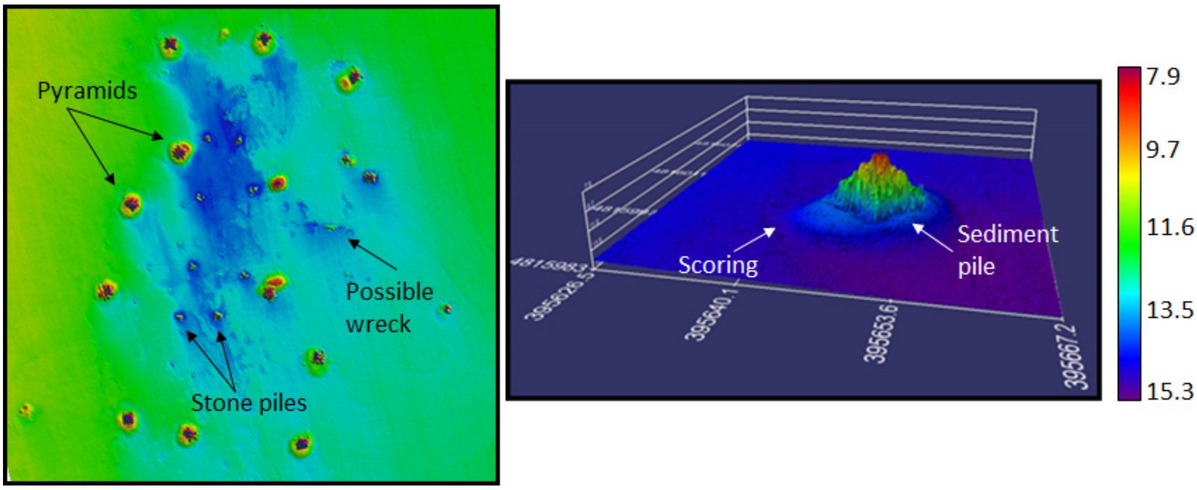


Figure 19. Adriatic Sea: acoustic images of an artificial reef showing the modification of sediment distribution induced by the artificial substrates. The strong current has eroded the sea bottom at the south of the reef sets (violet area) raising each of them on a sediment pile (courtesy of CNR-ISMAR Ancona).

Artificial reefs may also cause negative impacts on fish resources, especially when reefs modify the spatial redistribution of exploitable biomass by simply aggregating it without increasing the total stock. This is the case of C-type C and D-type fish (see Section 5.2.2). In the absence of adequate management measures, a higher density at the reef increases the probability for this fish to be caught. Greater accessibility to the resources increases the potential fishing effort, leading to an increase of fishing mortality and, consequently, a decrease of the exploitable biomass in the area (Polovina, 1991).

Possible negative effects on the fish species inhabiting an artificial reef may derive from the ghost fishing generated by the entrapment of set nets on the artificial substrates and consequent loss of the gears. These nets will continue fishing for a certain time and entangled fish which die and rot may cause a degradation of the reef environment.

A further concern regards the potential contribution of artificial reefs to the introduction and expansion of non-indigenous species, including parasites, as the artificial reefs may provide these invasive species with a suitable habitat which previously did not exist. Artificial reefs may also provide connectivity between areas where invasive species are present and areas where their occurrence has not been documented. A risk analysis should be performed prior to the deployment of an artificial reef in order to evaluate the vulnerability of the designed reef site towards invasive non-indigenous species, in terms of known outbreaks and occurrence of invasive species in regions close or adjacent to the proposed reef sites.

From a socio-economic point of view, in the absence of an adequate management plan that regulates the access and catch rates at the reef, the deployment of an artificial reef might increase conflicts between the potential users of the reef and cause an overexploitation of the reef resources.

Table 2 reports a list of the possible negative impacts generated by artificial reef deployment. Most of these impacts can be mitigated or avoided thanks to careful planning, appropriate site selection and construction materials, and a correct reef design taking into account both the purpose of the reef and the oceanographic conditions at the proposed site.

Table 2: List of possible negative impacts of artificial reefs and actions to be undertaken to avoid or mitigate such impacts

	Impact	Source	Effect	Duration of the effect	How to mitigate / avoid the impact
Environmental impacts	Increase of contaminants into the sediments	Work vessels and equipment during the reef installation	Degradation of the marine environment Possible accumulation of contaminants into the food chains	Short-medium	Reduce as much as possible the duration of deployment operations
	Increase of contaminants in the marine environment	Reef materials	Degradation of the marine environment Possible accumulation of contaminants into the food chains	Long	Adequate choice of reef materials Adequate cleaning up of structures of opportunity (vessels, aircrafts, etc.)
	Increase of turbidity	Sediment movement during the reef installation	Alteration of photosynthesis of algae, seagrasses and corals	Short	Adopt deployment techniques that limit sediment movement
	Modification of bottom currents	Presence of the reef	Modification of sediment distribution Modification of sediment grain-size Scoring and subsidence of the reef structures Modification of sensitive habitats in the reef surroundings	Long	Accurate study on currents and sediments at the proposed reef site
	Increase of organic content into the sediments	Presence of the reef	Modification of sensitive habitats in the reef surroundings	Long	Accurate studies on water circulation at the proposed reef site
	Displacement of natural sensitive habitats	Unintentional deviations from the planned deployment	Reduction of ecosystems	Long	Forecast a buffer surrounding the reef Place the reef far from sensitive habitats
	Increased predation on some fish species	Design of the reef units Increased availability of preys	Increase of natural mortality	Medium-long	Forecast the presence of holes and refuges of different size in planning the reef units
	Introduction of non-indigenous, invasive species	Inadequate positioning of the artificial reef	Reduction of local communities	Medium-long	Analysis of potential risks prior to reef deployment
	Increased catchability of some fish species	Presence of the reef Inadequate design of reef modules for large reef fish	Increased fishing mortality Depletion of stocks	Short-medium-long	Studies on the ecological features of the fish that can be attracted by the artificial reef Forecast the presence of holes and refuges of different size in planning the reef units Develop adequate plans to regulate exploitation of the reef resources
	Ghost fishing	Inadequate choice and/or displacement of artificial reef units	Increased fishing mortality Habitat degradation	Short-medium	Avoid placement of units provided with iron/steel fishing devices inside the artificial reef when the reef is constructed for enhancing small-scale fisheries Long-term monitoring and eventual collection of ghost fishing gears as mitigation measure
	Conflicts between reef users (e.g. recreational and professional fishers)	Lack of adequate management plan of the reef site	Inadequate exploitation of the reef resources	Short-medium-long	Development of an adequate plan to regulate access to reef resources

	Impact	Source	Effect	Duration of the effect	How to mitigate / avoid the impact
Socio-economic impacts	Conflicts with other human activities at sea	Inadequate positioning of the artificial reef	Failure in the management of human activities at sea	Short-medium-long	Study on the human activities that take place at and in the proximity of the proposed reef site

Given that most artificial reefs will have a design life in excess of 30 years, the long-term management of the reef should be considered carefully during the planning phase. Ownership, responsibility and liability need to be considered, and possible mitigation actions forecasted. In the short term, careful planning during the installation phase of the reef should mitigate a majority of concerns aligned with construction (increased turbidity, pollution for installation plant and equipment, etc.).

7. Methodologies to assess effectiveness and impacts of artificial reefs and standardized monitoring procedures

A critical element in understanding how artificial reefs can be integrated into a more general marine resource management framework is the ability to evaluate the performance of artificial reefs. Despite significant developments in construction and design, artificial reef projects have been criticized for a lack of planning in the development of adequate monitoring programmes that will provide fisheries scientists and managers with the information required to test objectives (Claudet and Pelletier, 2004). Consent conditions placed upon artificial reef development provide the clearest basis to establish a monitoring programme that will address the primary aims of the reefs installation. Clearly establishing the aims for reef construction will help authorizing authorities set these subsequent conditions of consent. Once set, these conditions may easily be translated into monitoring programmes with clearly defined (and achievable) outcomes.

Monitoring programmes should be part of management plans aimed to ensure that the artificial reef is sustainably managed and that its operation does not have negative impacts on the marine environment and fish surrounding communities. These programmes should aimed to verify that:

- water quality is maintained;
- the structural integrity and stability of the reef infrastructure is maintained over time;
- there is no increase of contaminants in the environment (water and sediments);
- the occurrence of pests and/or other invasive species is minimized and, if these events do occur, prompt reporting, management and/or remedial action will be implemented;
- the ecological, social and economic goals of the reef are achieved;
- navigational safety is maintained.

Elements that help clarify a Mediterranean standardization of monitoring programmes for artificial reefs are provided hereafter.

7.1. Critical aspects in monitoring plans

Scientific research on artificial reefs has gathered pace internationally since the 1950s. Many researchers have attempted to demonstrate the effects of anthropogenic manipulation of habitat complexity, but much of the research has been compromised by associated legal or financial constraints that limited the ability to develop formal hypothesis testing (Bortone, 2006), not providing acceptable levels of replication (Kock, 1982; Fabi and Fiorentini, 1994; Fujita *et al.*, 1996; Charbonnel *et al.*, 2002) and/or not avoiding pseudoreplication – defined as the use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated (though samples may be) or replicates are not statistically independent (Kock, 1982; Bortone *et al.*, 1994; Jensen *et al.*, 1994).

Research conducted over the past four decades indicates that resource managers would be in favour of using artificial reefs as part of an alternative management strategy, but they would need information at different levels proving the effectiveness of artificial reefs for certain purposes (e.g. fisheries management). While the general opinion is that it is necessary to know every aspect on artificial reefs to fully appreciate their potential role in the marine ecosystems and to include them into management plans, a more realistic approach would be to focus research on the gathering of data on specific areas of interest that are based around the primary goals of the artificial reef construction (discussed in detail in Chapter 5).

Therefore, a performance monitoring plan should be developed during the first steps of the planning process of an artificial reef. This plan should focus on parameters that define the success of the artificial reef based on the reef objectives, and must forecast collection of data before and after the reef deployment, both at the reef site and on adjacent natural habitats. Scientific assessment of artificial reefs should be designed and undertaken by experts in ecological and biological marine sciences during the reef planning phase and implemented prior the artificial reef construction or on already existing artificial reefs. As scientific objectives surrounding complex ecological questions are very broad and include a number of more specific goals, the type and quantity of data to be collected depend on the objectives of the artificial reef and the kind of questions to be answered.

7.2. Monitoring methods

Sampling methods used in studies associated with artificial reefs fall into two broad categories: non-destructive and destructive methods.

7.2.1. Monitoring the physical performance of artificial reefs

As already explained in Section 4.1, the introduction of artificial reefs into the marine environment acts as an open system with exchange of material and energy, altering the physical and biological features of the area where they are deployed. Artificial reefs can modify flow velocity and create turbulent intensity in and around the vicinity of the structures, which can lead to scour and changes in sediment accumulation in the surrounding area. The environmental changes on the adjacent seafloor can, in turn, physically affect the artificial structures. Thus the stability, and hence the efficiency, of an artificial reef will depend on the balance of scour, settlement and burial resulting from ocean conditions, as well as on human activities over time.

For example, to prolong the effects of a protection artificial reef over time, it is important that the reef units maintain their spatial position and do not burrow too much into the sediment (Manoukian *et al.,* 2004).

Long-term monitoring of the physical performance of artificial reef systems is essential to understand how the sedimentary and oceanographic conditions (collectively known as coastal process associated with wave and current movements) affect different types of artificial reefs and how the physical conditions of the reef influence the succession of reef communities over time.

Acoustic systems (single-beam echosounder, MBES and side scan sonar) are efficient tools capable of monitoring the environmental (physical and biological) evolution around artificial reefs (Fig. 20), whereas visual dive and remotely operated vehicle inspections can be limited by water turbidity.

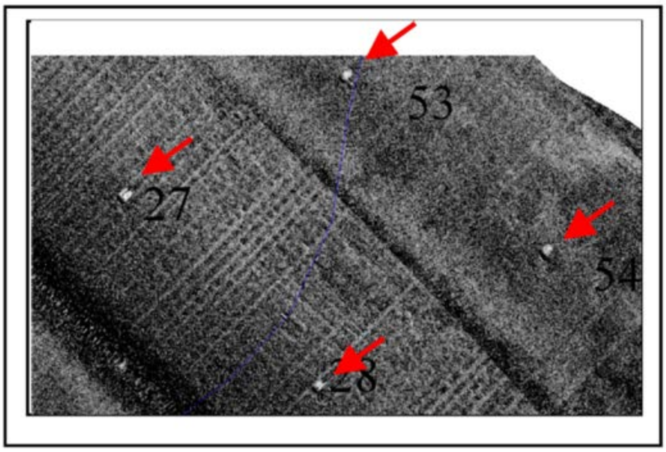


Figure 20. Side scan sonar georeferenced image of units in the protection Santanyi artificial reef, Mallorca, Balearic Islands, Spain (courtesy of Balearic Islands Government).

However, techniques such as single-beam echosounder and side scan sonar have spatial limitations and navigation uncertainties of the towfish as well as difficulty in three-dimensional positioning of the towfish during a survey. Conversely, high-frequency MBESs offer the potential of detecting and defining the fine-scale distribution of artificial reef units from a ship equipped with good control of sonar positioning through a survey, due to the very accurate navigation available from DGPS or similar systems (Fig. 21).

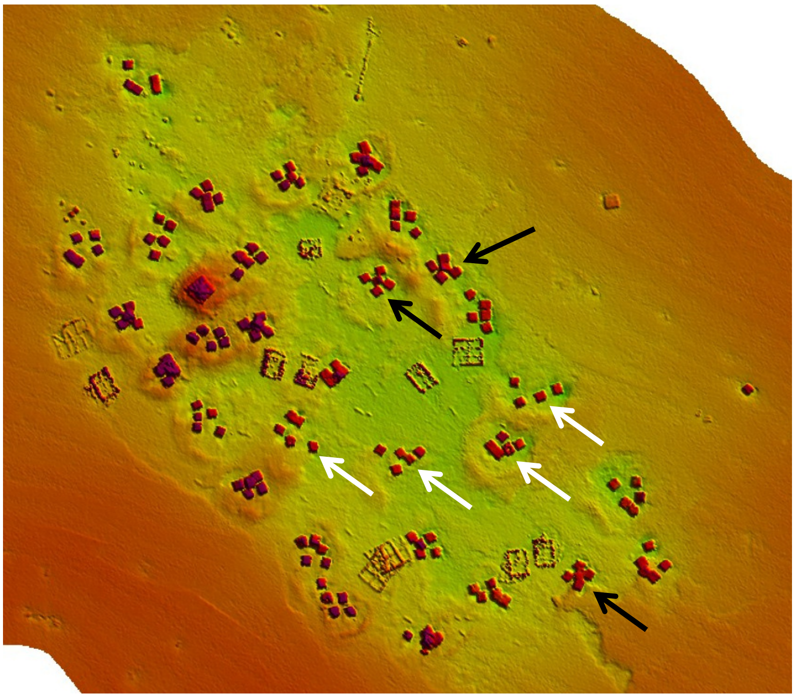


Figure 21. Multibeam echosounder image of on artificial reef in the Adriatic Sea, Italy, 21 years after deployment. Some reef sets have maintained their original structure (black arrows), while others have collapsed (white arrows) (courtesy of CNR-ISMAR Ancona).

These high-resolution systems are able to acquire 100 percent coverage of seabed geology and geomorphology over relatively broad spatial scales, offering an unprecedented level of resolution, coverage and spatial definition. In recent years, the application of acoustic-mapping methodology, in particular the use of acoustic ground-discrimination systems in conjunction with bottom sampling, has become common practice in monitoring and mapping seabed habitats (Naar *et al.*, 1999; Cochrane and Lafferty, 2002; Foster-Smith *et al.*, 2004; Manoukian *et al.*, 2004, 2011; Jarrett *et al.*, 2005; Jordan *et al.*, 2005; Sala *et al.*, 2007; Freitas *et al.*, 2008).

Because acoustic data are less able to detect changes in the biological components of the seabed, classifications of different seabed environments tend to be driven largely by physical criteria (Kostylev *et al.*, 2001; Freitas *et al.*, 2003).

Mapping should start before the artificial reef deployment, be repeated just after the immersion of the structures to verify their right position, and continue over all the life of the artificial reef. Acoustic mapping of the seafloor before reef deployment not only provides a baseline against which post-installation assessments of sediments changes (scour and accumulation) can be based but is also very important to identify any unknown obstruction in the area which may have cultural or historical significance (i.e. ship wrecks) as well as any unchartered natural rocky reef.

7.2.2. Benthic communities

The deployment of new hard substrates may induce changes in the communities of the natural habitats as well as the development of new epibenthic communities (fauna and algae) which will colonize the artificial structures.

7.2.3. Soft-benthic communities

Artificial structures in the marine environment have the potential to influence adjacent soft sediment assemblages in several ways. This may be done indirectly, through the alteration of the physical and/or biological properties of the environment or through the direct placement of the structure including direct loss or disturbance of infaunal assemblages, changes to sediment characteristics, increased predation by fish and decapods on soft-bottom infauna, organic enrichment of sediments from excretion, and detritus of reef associated organisms. On the other hand, the organic matter produced by fish and other organisms associated to the reef represents additional food for many detritivorous and deposit-feeder benthic species, which tend to move close to the artificial reefs. In turn, these species may be preyed by other carnivorous benthic organisms, and both of them by fish. In addition, mollusc shells or other organisms (e.g. serpulids, calcareous algae) falling down from the artificial substrates to the surrounding seabed contribute to diversify the bottom habitat and, consequently, the natural soft-bottom communities.

Most of the research on infauna surrounding artificial reefs dealt with the macrofauna group-size components, but meiofauna should also be considered, being an important component of the interstitial infauna of the sublittoral sand sediments (Fenchel, 1978) that may significantly affect the structure of the macrofauna communities (Watzin, 1983).

As a primary aim is to assess the radius of influence of an artificial reef on the surrounding seabed community, samples should be collected as close as possible to the reef edge and at increasing distances from it (Fabi *et al.,* 2002). The same should be done inside the reef to verify the influence of the different modules employed (Fig. 22). An adequate number of replicates should be forecasted at each site and at adequate time periods to assess spatial and temporal (e.g. seasonal, annual) variability.

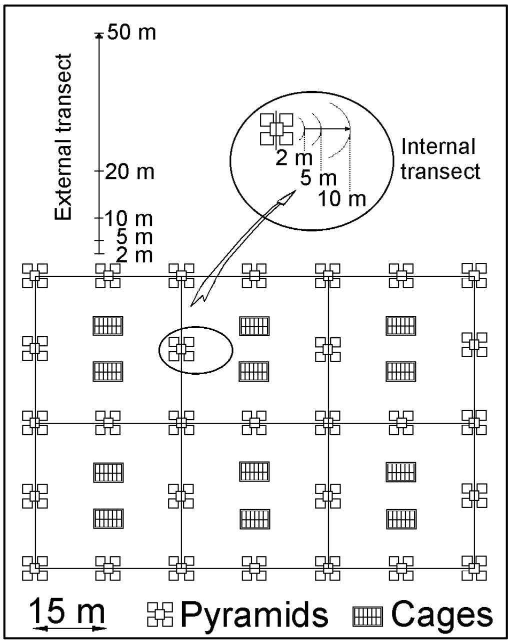


Figure 22. Example of sampling plan of the soft-bottom benthic communities at an artificial reef (from Fabi *et al.,* 2002).

7.2.4. Epibenthic and algal communities

The technical features of the artificial reef, such as the materials, shape, size and surface rugosity, should be taken into account in evaluating the epibenthic communities. Beside the animal component, the study on macroalgae is also important to assess the ecological role of an artificial reef, for example in terms of increasing oxygen production; trapping of sediments, thus increasing food supply for detritivores; and creation of nurseries and food sources for herbivorous fish (Falace and Bressan, 1996). Three main aspects should be assessed: presence/absence, luxuriance and fertility.

As in the case of soft-bottom communities, adequate spatial and temporal sampling is required as well as a sufficient number of replicates in space and time. The number and size of samples depend on the spatial variability: a higher variability requires more and larger samples (Moreno, 1996). Sampling must be simple and fast since it must be carried out by scuba divers. For this reason, it is important that the protocol is standardised and well defined.

7.2.5. Sampling methods

Non-destructive methods

Underwater observations: *in situ* observations include both qualitative and quantitative methods to establish lists and zonation patterns, and include observations or photographic techniques taken by divers, if depth permits, or by remote surface deployed cameras. Photography may be used to estimate the fauna and flora species composition, the number of organisms, the percent cover and the relative density of the sessile community. Moreover, it allows for an objective evaluation and the creation of a reference collection.

Such methods can be used for soft- and hard-bottom communities, and are useful for dominant and large organisms. However, they are likely to underestimate small or understory components of the community.

Moreover, the records obtained through these techniques can be affected by low taxonomic precision, especially for small-sized organisms and algae. In addition, these methods require a good water transparency and, in temperate waters, may be difficult to be applied in all seasons.

Destructive methods

Grab and box-corer samplers: these instruments are usually employed to sample communities inhabiting the soft-bottoms outside an artificial reef and between the structures constituting the reef. Grab samplers (e.g. Van Veen) and box corers have a known volume and can be appropriate in quantitative studies. Moreover, they are surface operated and do not require underwater work; however, their positioning on the seabed is not precise. In addition, the penetration of these instruments inside sandy bottoms may be difficult. Box corers have a smaller capacity than grabs and usually require a high number of samples to obtain an adequate sediment volume.

Dredges: they can be used to sample soft-bottom communities outside the artificial reef; however they cannot be used inside the reef due to the presence of the reef structures. Dredges are not able to adequately sample predefined quantities of sediment and hence not useful in the case of quantitative studies (Castelli *et al.*, 2003).

Suction samplers: these samplers are used to investigate soft-bottom benthic communities, but may be useful for interstitial fauna living on the horizontal walls of the hard substrates (Spagnolo *et al.*, 2004; Fabi *et al.*, 2006). These instruments allow for sampling the exact sampling point because they are directly operated by scuba divers, but they may require a great sampling effort to collect samples of adequate size and/or a sufficient number of replicates.

Scraping technique: this technique is commonly employed to sample hard-bottom communities (animals and algae). Similar to the suction sampling, it has the advantage to sample at the sample site but it may require a greater effort by divers. In addition, part of the sample is likely to be lost, especially small-sized organisms, due to underwater currents.

7.2.6. Fish assemblage

7.2.7. Sampling methods

Non-destructive methods

Underwater visual census (UVC): UVC by divers is historically the most common non-destructive method used, and a range of techniques to monitor fish assemblages in a variety of shallow marine habitats has been developed (Bortone and Kimmel, 1991). The most common are:

- *Strip transect:* the diver swims along a transect of pre-established length in a pre-established time interval listing the species encountered.
- *Point count*: the diver stands at a fixed point and enumerates the organisms observed within a prescribed area or volume in a pre-established time interval.
- *Species-time random count*: this method is based on the principle that abundant species are likely to be encountered first than the rarer ones. The observer swims randomly over the survey area for a predefined time period either simply recording the species encountered or listing them in the order in which they were initially seen.
- *Combinations of methods*.

In situ visual methods are relatively rapid, provide adequate levels of replication and are capable of recording a broad suite of variables, e.g. relative abundance, density size structure species composition and habitat characteristics (Bortone *et al.*, 2000; Samoilys and Carlos, 2000). However, the limitations of diver-based methodologies have been well documented (Thresher and Gunn, 1986; Lincoln-Smith, 1988, 1989; Bombace *et al.*, 1997; Thompson and Mapstone, 1997; Kulbicki, 1998) and relate to the physical limitations (e.g. water depth and visibility) and species-specific sources of "detection heterogeneity" (Kulbicki, 1998; Macneil *et al.*, 2008), which can be summarized as the ability of the diver to see fish accurately and record their presence under variable conditions (Sale, 1997). Moreover, the different fish species react in different ways to the presence of divers: some escape whereas others come closer, making it difficult to carry out a census with the same level of accuracy.

Baited remote underwater video (BRUV): recent innovations in the development of video technology have resulted in the widespread use of BRUV as a means to monitor fish populations in a variety of habitats (Cappo *et al.*, 2006). BRUV systems have however inherent biases such as difficulties in determining the area sampled due to variables associated with the dispersion of bait (Priede and Merrett, 1996, 1998; Bailey and Priede, 2002), conservative relative abundance estimation (Farnsworth *et al.*, 2007), reliance on acceptable visibility and an inability to detect more cryptic reef associated species (Watson *et al.*, 2005).

Hydroacoustic techniques: the most recent advancement in artificial reef research involves using stationary or mobile hydroacoustic technology (e.g. echosounders for fish, MBES) to study fish abundance, distribution and behaviour in specific areas.

Echosounders for fish have been successfully employed in surveying fish assemblages at hydroelectric facilities in riverine environments and around oil and gas platforms (Thorne *et al.*, 1990; Thorne, 1994; Stanley *et al.*, 1994; Stanley and Wilson, 1998; Soldal *et al.*, 2002). However, applying this technique to artificial reefs has been very limited thus far (Thorne *et* *al.*, 1989; Fabi and Sala, 2002; Sala *et al.*, 2007; Kang *et al.*, 2011). The advantage of the stationary hydroacoustic methods in respect to the mobile method is that in the former, when strategically placed and combined with computerized data records, the transducer arrays allow to collect long-term, time-series data along the entire water column or at specific depths.

The newer generation of MBES is able to detect the seafloor and the water column at the same time. An aspect that is commonly ignored when assessing the fish assemblage at an artificial reef is the current state of the structures. Studies usually refer to the initial arrangement of the artificial substrates, but do not take into account movements and alterations that may occur over time due to environmental and anthropic factors, although the arrangement, distance, shape and dimensions of the reef units and/or reef sets can strongly affect the composition and behaviour of the reef fish assemblage (Nakamura, 1985; Bombace, 1989; Okamoto, 1991). Relief imagery produced from multibeam bathymetric data can provide valuable and detailed basemaps for seafloor investigation and interpretation (Todd *et al.*, 1999; Mosher and Thomson, 2002), thus helping better understand the evolution of the fish assemblage associated to an artificial reef in respect to the status of the substrates. These data associated to the data recorded along the water column allow to detect the behaviour of fish inside the artificial reef and to map the spatial distribution and abundance of fish in respect to the reef structures (Fig. 23).

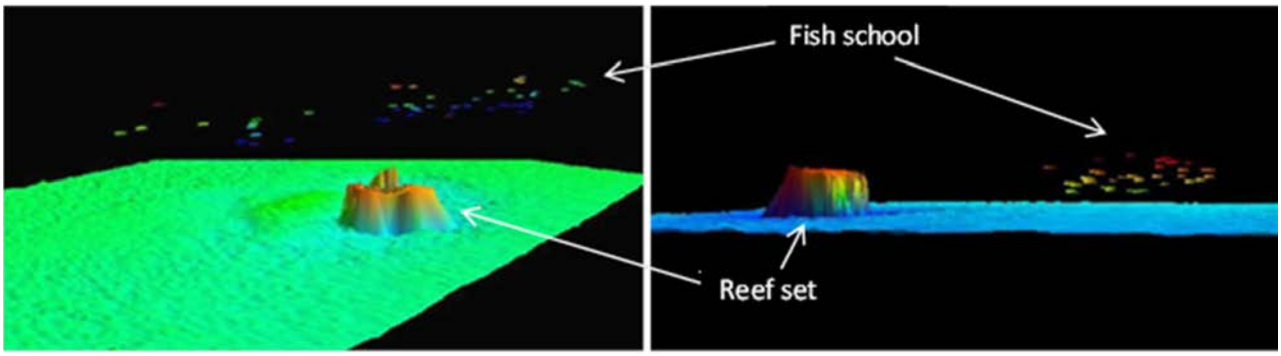


Figure 23: Multibeam echosounder images of fish schools around artificial reef structures in the Adriatic Sea, Italy (courtesy of CNR-ISMAR Ancona).

In general, the main disadvantage of hydroacoustic techniques is the difficulty of identifying the species, especially in a mixed-species assemblage such as that typically inhabiting an artificial reef.

Destructive methods

These methods include adaptations of commercial fishing techniques such as traps, longlining and setnetting (Gannon *et al.*, 1985; Kelch *et al.*, 1999) as well as trawling.

Trawling is the less suitable technique because, due to the physical presence of the artificial reef structures, it must be performed at a certain distance from the reef. Consequently, as the radius of influence of an artificial reef on the different species changes at increasing distances from it, trawling cannot allow to fully investigate the assemblage inhabiting the reef. Nevertheless, protection artificial reefs that aim to protect wide areas can be designed in such a way as to include a free internal zone where it would be possible to carry out surveys with towed gears. This is the case of an artificial reef constructed in an area of the Cantabric Sea and surveyed since 1984 to study fish demersal stocks and benthic macrofauna. The position of the artificial units was planned so to leave the survey area free. Artificial reefs consist in groups of concrete blocks with a separation of 130 m between blocks and of 2 km between groups of blocks. The surface area occupied by the blocks is less than 2 percent of the whole area (Fig. 24; Serrano *et al.,* 2011).

The advantages related to the use of fishing gears include the availability of specimens to study the effect of the artificial reef on growth, diet and sexual reproduction. Moreover, the possibility to sample at day and night and in each season over the year, independently from water transparency, allows studying the daily behaviour of species assemblages as well as the seasonal changes of the reef fish community.

Oppositely, the potential habitat degradation due to the use of fishing gears, the impossibility to observe the behavioural aspect of the species associated with the artificial reefs, and the possible underestimation in terms of both size and species due to the selectivity of the gear employed, are clear weaknesses of such approaches. Moreover, these methodologies are often prohibited in sensitive areas such as marine parks (Willis *et al.*, 2000; Lipej *et al.,* 2003; Cappo *et al*., 2004).

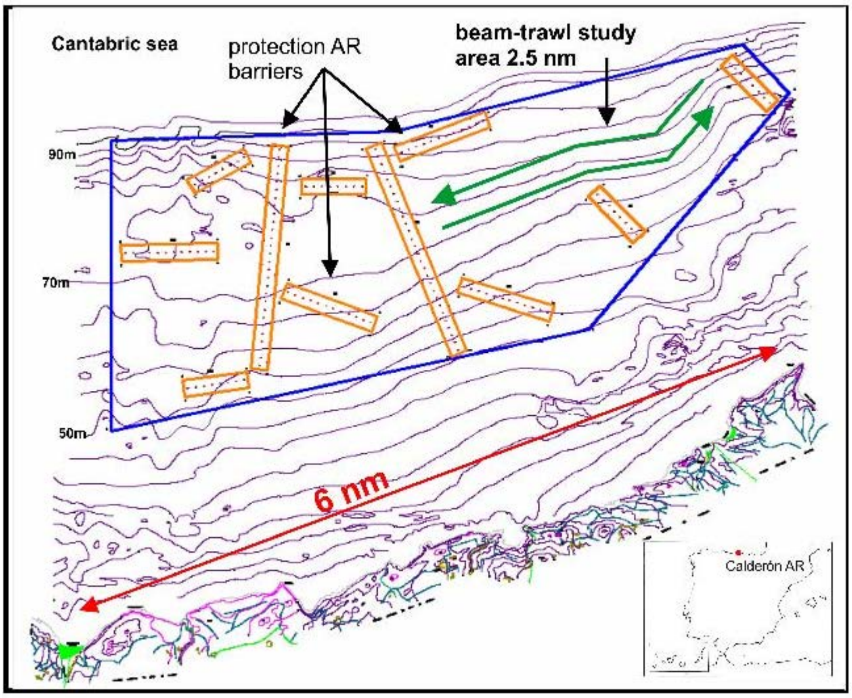


Figure 24: Protection artificial reef of Calderón, Cantabria coast, deployed in an area subjected to scientific trawl surveys, Spain (courtesy of J.J. Goutayer Garcia).

However, the crucial aspect in the investigation of the biological assemblages associated with artificial reefs is the capacity to standardize results from studies using different methodologies. For example, there are situations where one study uses UVC and another study uses experimental fishing surveys in the same area.

The new monitoring perspectives to assess the effects of an artificial reef refer to two critical points:

- no single technique is capable of completely describing the communities associated to an artificial reef;
- a combination of techniques should be employed and adjusted according to the morphological and geographical characteristics of the reef areas.

7.3. Statistical framework

Surveys must be designed taking into account the fact that fish assemblages and sessile resources associated with artificial reefs are both extremely patchy in distribution and abundance and variable in time. Patchiness and temporal variation are caused by processes that are external to the assemblage, in particular disturbances, changes in environmental factors (e.g. temperature and current speed and direction) and recruitment, in addition to processes operating within the existing assemblage.

The statistical framework which should be developed to better evaluate the community/assemblage biomass associated with artificial reefs, and hence determine the effectiveness of artificial reefs for the development of benthic communities, stock enhancement and fishery management, should be related to new and comprehensive statistical methods such as:

- Before-after control-impact (BACI)/after control-impact (ACI) and beyond BACI designs;
- Analysis of variance (ANOVA), multivariate analysis of variance (MANOVA), permutational multivariate analysis of variance (PERMANOVA) with uni- or multifactorial designs;
- Non-parametric methods (e.g. Kolmogorov-Smirnov test, Mann-Whitney U test, Kruskall-Wallis test, Wilcoxon matched pairs test, etc.);
- Time series analysis.

7.3.1. Statistical methodologies

7.3.2. BACI/ACI and beyond BACI designs

The development of beyond BACI designs (Underwood, 1991) has led to significant advances in the detection of changes due to the deployment of artificial structures. Such designs use multiple reference locations and the data are usually analysed with an asymmetrical analysis of variance due to the presence of a single location interested by the deployment of a new structure (artificial reefs, offshore platforms, etc.). In this approach, the influence of the new structure, if it exists, can be detected as a statistical interaction in the difference between the area interested by the deployment and reference locations from before to after the placement. Thorough discussions of beyond BACI designs, including several examples and their interpretation, are provided by Underwood (1991, 1992 and 1993). Further examples of the performance of BACI and beyond BACI procedures are illustrated by Hewitt *et al.* (2001), whereas Benedetti-Cecchi (2001) discussed an approach based on Monte Carlo simulations to optimize such complex designs. Stewart-Oaten and Bence (2001) examined a number of potential problems of beyond BACI procedures and emphasized a model-based philosophy to the analysis of impacts (Terlizzi *et al.*, 2010).

A possible advantage of beyond BACI designs is that they can be modified and applied in tests of impact when no data have been obtained before the purported impact and, thus, only “after’’ data are available. These ACI designs, though more limited in establishing cause-effect relationships between human interventions and responses of populations, have been widely used in environmental impact studies (Chapman *et al.,* 1995; Roberts, 1996; Lardicci *et al.*, 1999; Guidetti *et al.*, 2002). More specifically, in the absence of “before’’ data, it may be possible to detect consistent differences between one or more modified locations and several reference locations, although it is generally not possible to attribute causation to any particular event, historical or ongoing, for such differences.

A detailed description of how to deal with asymmetrical data and a discussion of the problems associated with detecting impacts when only “after’’ data are available are provided by Glasby (1997).

7.3.3. ANOVA and MANOVA (PERMANOVA)

The analysis of variance has been utilized since the beginning of the development of studies about artificial reefs (Fabi and Fiorentini, 1994). When the replication is appropriately designed and the assumptions are fully met, this method provides a robust statistical framework to evaluate the changes in both fish and benthic communities. The main issue is that, especially in multivariate analysis (MANOVA), it is quite unrealistic that data are normally distributed. An alternative to this traditional approach that does not rely on such strict assumptions is to use a permutation test (PERMANOVA). A permutation test calculates the probability of getting a value equal to or more extreme than an observed value of a test statistic under a specified null hypothesis by recalculating the test statistic after random re-orderings (shuffling) of the data (Anderson, 2001).

Non-parametric multivariate and univariate procedures have emerged in recent years, providing useful statistical methods that have been widely adopted for analysing areas characterized by the deployment of artificial structures. Similarly to permutation tests, an important feature of these methods is that they do not require the assumption of normality. This is a requirement that very often is not met by data consisting of counts of species, abundances or percentage cover of organisms (Legendre and Legendre, 1998).

7.3.4. Non-parametric methods

Non-parametric tests are numerous and have different purposes. In the following paragraph, short descriptions of the most utilized tests are provided. The Kolmogorov-Smirnov test assesses the hypothesis that two samples were drawn from different populations and it is usually employed to compare frequency distributions. Unlike the Mann-Whitney U test, which tests for differences in the location of two samples (differences in means, differences in average ranks, respectively), the Kolmogorov-Smirnov test is also sensitive to differences in the general shapes of the distributions in the two samples (i.e. to differences in dispersion, skewness, etc.). Thus, its interpretation is similar to that of the Wald-Wolfowitz runs test. The Kruskal-Wallis ANOVA by ranks test assumes that the variable under consideration is continuous and that it was measured on at least an ordinal (rank order) scale. The test assesses the hypothesis that the different samples in the comparison were drawn from the same distribution or from distributions with the same median. Thus, the interpretation of the Kruskal-Wallis test is basically identical to that of the parametric one-way ANOVA, except that it is based on ranks rather than means. The Wilcoxon matched pairs test assumes that the variables under consideration were measured on a scale that allows the rank ordering of observations based on each variable (i.e. ordinal scale) and that allows rank ordering of the differences between variables (this type of scale is sometimes referred to as an ordered metric scale).

7.3.5. Time series analysis

Time series analysis is used when observations on artificial reefs are made repeatedly and over long time periods (more than 20–25 years). One goal of this analysis is to identify patterns in the sequence of samples over time, which are correlated with themselves. Another goal in many research applications is to test the impact of one or more interventions (for example the enlargement of an artificial reef or the opening of the reef to fishers). Time series analysis is also used to forecast future patterns of events or to compare series of different kinds of events and find out possible cause-effect correlations between habitat and environmental parameters.

7.3.6. Spatial and temporal replication

The temporal and spatial scale of sampling is essential to separate reef effects from background variability. While some studies have examined how the distribution of artificial reefs relates to habitat use and to the development of prey resources for resident species, few have explicitly attempted to isolate reef effects. An absence of background pre-deployment data (Clark and Edwards, 1999), erroneous and inappropriate experimental design (Alevizon and Gorham, 1989), as well as infrequent sampling, e.g. only once per season (Santos and Monteiro, 1998), have also cast doubts over recorded changes in fish abundances.

The spatial extent of sampling depends on the size of the area designated for artificial reef placement. Obviously, a number of reference sites without any artificial reef and having the same environmental characteristics (e.g. grain-size, depth) should be sampled at the same time in order to assess the effects of the artificial reef in the environment. Indicating the correct number of reference sites is quite challenging because it depends on a variety of factors, first of all the aim of the study and the spatial scale considered. However, as a rule of thumb, reference site number should not be less than three to provide enough data to apply one of the statistical methods listed before.

Whatever the typology of the study, the hypothesis to be tested and the ultimate use of the data from sampling, spatial replication is a mandatory component of any kind of investigation. The large variability in numbers and varieties of species from place to place at many spatial scales creates fundamental problems for determining which scale of replication is necessary. When there is a doubt about the relevant spatial scale, it is suggested to use a design that can detect changes or differences at one or more of the possible scales.

In studies with frequent sampling, the high variability in abundances of individual species is an evidence of key events such as settlement, migration and mortality. The same experimental design sampled at less frequent intervals will fail to detect these events, which are fundamental to distinguish attraction and production. Artificial reefs and reference sites should be visited at intervals that are relevant to life history events, e.g. every month or every two months, to permit comparisons between and within seasons and detect abundance changes related to recruitment and mortality.

To test seasonal or other *a priori* selected scales of temporal variation, temporal variation among the factors of interest should be compared to temporal variation within each factor of interest. In other words, the temporal variation among seasons must be compared to the magnitudes of variation that occur in each season. To measure such variability, it is essential to collect samples at an adequate number of times within each season. With two or more scales of temporal sampling, seasonal or other long-term trends can be identified against background noise. Where there is no measure of shorter-term temporal variation and such variation is large, quite spurious seasonal (or other temporal) patterns will be seen in the data. Moreover, at a shorter temporal time scale, the variability due to the photoperiod needs to be considered in studies on the horizontal and vertical movements of reef fish through the water column.

Different scales of temporal sampling are extremely important to identify environmental impacts. Disturbances to the environment may either be short-lived (pulse disturbances) or persist for long periods of time (press disturbances) (Bender *et al.*, 1984). The responses of organisms to either type of disturbance may be relatively short-term (i.e. a pulse response); for example, abundance may rapidly increase but soon drop to normal levels, irrespective of whether the disturbance persists or ceases. Alternatively, populations may show long-term responses (i.e. press responses) to continuing disturbances (because the disturbance continues to exert an effect) or to pulse disturbances (because the disturbance, although ended long ago, caused long-term changes to some other environmental or biological variables).

8. Socio-economic effects of artificial reefs

The primary reason for artificial reef deployment is to serve human uses, such as commercial and recreational fishing and scuba diving. Even though the need of evaluating the socio-economic effects associated to the deployment of artificial reefs has been highlighted since the beginning of the 1980s (Bohnsack and Sutherland, 1985), there is still a general lack of studies dealing with this issue, and most of them focus on areas with the greatest concentration of artificial reefs, such as Japan and the United States (Milon, 1988; Rhodes *et al.,* 1994; Ditton *et al.,* 1995; Simard, 1997; Bell *et al.,* 1998; Milon *et al.,* 2000). Independently of its purpose, the performance and efficacy of an artificial reef is usually judged on the basis of public satisfaction. The collection and evaluation of socio-economic data is useful to quantify the usage and public benefits of an artificial reef, thus helping justify construction and maintenance costs, and providing information for the successful management of the reef (Milon *et al.,* 2000).

8.1. Socio-economic assessment

Socio-economic assessment of artificial reefs should be conducted by experts in social and economic sciences, either prior to the artificial reef construction or once the artificial reef already exists. This exercise involves the following phases (Milon *et al.*, 2000):

a) objective identification;
b) development of survey instruments;
c) collection and analysis of data.

Socio-economic objectives are very broad and include a number of more specific goals, such as those connected to ecological and environmental issues.

The typology and quantity of data to be collected depend on the objectives of the artificial reef and on the kind of questions to be answered. The data collection phase includes three steps (Table 3):

1. **Monitoring of utilization patterns**: this step consists in evaluating the broad goals of the artificial reef project (e.g. increase of the number of sites suitable for divers and/or recreational fishing, increase of near shore grounds for local fisheries, replacement or restoration of damaged natural habitats). The techniques to be used for data collection and evaluation are: i) direct observation of activities in the area; ii) on-site interviews; iii) mail or phone surveys. These techniques can be applied either individually or in combination. Data collection should not be conducted on a one-time basis or over short time periods as the perception of stakeholders may be easily influenced by events and could change in a few days.

2. **Impact assessment**: this assessment includes social and economic assessment and aims to understand the social and economic importance of an artificial reef for the local communities by assessing the changes induced by the project and evaluating whether these changes fit with the specific objectives of the reef. For example, if the goal of an artificial reef project was to support the local economy by improving recreational fishing and attracting non-resident fishers, the achievement of this goal could be evaluated through an economic analysis that compares the non-resident recreational activity before and after the reef deployment. In order to assess the social and economic

changes produced by the deployment of an artificial reef, it is necessary to know the previous conditions, taking into account different dimensions: historical, cultural, demographic, social, economic and ecological.

3. **Efficiency analysis**: this step aims to evaluate the economic performance or net benefits of the artificial reef. Efficiency analysis can be classified as either cost-effectiveness or cost-benefit evaluation. The former is aiming at determine whether a project can produce, or has produced, the expected benefits at the least cost, while the latter evaluates whether the benefits of the project exceed the costs. Both analyses provide information on whether the reef project is economically sustainable. They can also be used to compare the efficiency of different artificial reef projects or the economic performance of the reef project with respect to other types of initiatives.

Table 3. Types of socio-economic assessment (from Milon *et al.*, 2000).

Step 1 – Monitoring
Questions to ask: • Who uses the artificial reef and its resources? • When does the use occur? • Where does the use occur? • Why does the use occur? Techniques to be used: • Data collection and analysis from site observations, interviews, mail and/or phone surveys
Step 2 – Impact assessment
Questions to ask: • Which changes, if any, are measurable in social or economic activities due to the reef deployment and use? • Where do changes occur? • Why do changes occur? Techniques to be used: • Economic analysis, input/output analysis, social impact analysis
Step 3 – Efficiency analysis
Questions to ask: • Are the objectives of the projects being met at the least possible cost? • Does the monetized value of the project's benefits exceed the project's costs? Techniques to be used: • Cost-effectiveness analysis • Cost-benefit analysis

8.2. Stakeholder analysis

The deployment of an artificial reef can affect many human activities, hence a variety of stakeholders. Possible stakeholder groups are: recreational fishers, recreational divers, professional fishers, professional divers, resource managers, scientists, environmental groups (Milon *et al.*, 2000). It is important to note that the term “stakeholder” does not only refer to the groups which can obtain benefits from artificial reef deployment, but also to those which are opposed to the reef project (e.g. environmental groups).

In several countries, the majority of artificial reefs are public resources developed and managed by public authorities, and several users can benefit from them. However, in such situation, it is often difficult to manage the use of artificial reefs, and congestion may likely occur with negative impacts on the reefs effects (see Chapter 9).

Stakeholder analysis can be useful to either identify the most relevant stakeholder groups or understand their position towards the reef project. It also helps identify incompatible uses of the reefs and potential sources of conflicts. Such information may support managers to evaluate the importance of each group in the development of an artificial reef project and, once the reef has been constructed, plan adequate management measures to avoid or reduce conflicts and assure that non-target stakeholders are not negatively affected by the reef deployment.

9. Artificial reef management: control, surveillance and maintenance

Like other types of aquatic environments, artificial reefs may require post-installation management to make sure that they provide the desired outcomes for both biological resources and users. Additionally, effective management can help reduce potential risks such as damage to fishing gear, injuries to recreational divers visiting the reef, decomposed materials or movement of the reef units off-site.

Therefore, an adequate management plan should be developed prior to the deployment of an artificial reef. The objectives of management plans are to ensure that the artificial reef is sustainably managed and that its operation does not have a significant impact on the marine environment or surrounding community. The management plan should guarantee that the commitments made in pre-planning assessments (such as environmental assessments) and any approval or licence conditions are fully implemented. These plans should clearly cover submanagement plans, research and monitoring programmes, and protocols that address any potential environmental impact identified.

The management plan should include simple actions, such as to indicate the reef location on nautical charts in order to avoid damages to fishing gear, to provide user guidelines (e.g. diver safety guidelines) to prevent injuries to people diving at the artificial reef, and to establish technical measures aimed to regulate access and exploitation at the reef site.

Physical, biological and socio-economic monitoring is a key element of the management plan as it allows assessing the structural performance of the artificial reef over time and whether the artificial reef provides the expected benefits from the ecological and environmental point of view, and evaluating the efficiency of the applied control measures.

The involvement of stakeholders in artificial reef management is crucial. Professional and recreational fishers as well as divers can provide support in reef monitoring and evaluation. Applied research is another key element in artificial reef management programmes because it provides assistance in monitoring the activities carried out at the reef, in evaluating the efficacy of the adopted management measures and, where necessary, in identifying actions to be undertaken as well as alternative management options.

Given the scarce literature concerning the management of artificial reefs, the purpose of this chapter is to propose possible management strategies for the different types of artificial reefs.

9.1. Protection artificial reefs

Generally, protection artificial reefs do not need to be subjected to any control or management measures since they act by themselves as a management tool to impede illegal trawling/dredging in sensitive habitats. Nevertheless, they would need a regular monitoring to verify their structural performance.

9.2. Restoration artificial reefs

Considering that the main purpose for the placement of this type of artificial reefs is the recovery of depleted habitats and ecosystems of ecological relevance, their access should be totally forbidden to any kind of activity, except for research, which should also monitor the physical conditions of the reef.

9.3. Production, recreational, and multipurpose artificial reefs

There is evidence that the deployment of these types of artificial reefs cannot be successful if it is not associated to site-specific management plans which regulate their exploitation (Milon, 1991; Grossman *et al.*, 1997). Unregulated access may lead to overexploitation and to a rapid depletion of the reef resources as well as to conflicts within and between user groups. This usually happens when artificial reefs are created by public agencies in public waters without effective restrictions regarding access by different user groups (Milon, 1991) or where there is a lack of control to assure that the restrictions are respected.

User conflicts can be generated by stock effects and congestion effects. The former may occur from overexploitation of all species or particular species at an artificial reef site. The latter occurs when the activities of different users interfere with each other and may result from either incompatible uses (e.g. recreational and commercial fishing), incompatible fishing gear or the presence of too many users in a limited site. Stock and congestion effects are not mutually exclusive (Samples, 1989).

Several basic options for artificial reef management can be identified (Fig. 25):

1) Selective access control: it may consist in the establishment of property or user rights whereby local fishers communities or recreational associations would be co-responsible with government agencies for regulating access and monitoring both the activities which are carried out at the artificial reef and the physical performance of the reef structures. It is often not feasible due to political and institutional constraints which explicitly forbid discrimination between different groups of users (Whitmarsh *et al.*, 2008). This measure is efficiently applied in Japan, where fishers' cooperatives are granted exclusive commercial rights to regions of the coastline, thus prohibiting other user groups from harvesting from artificial reefs (Polovina and Sakai, 1989; Simard, 1997).

2) Gear and catch restrictions: this measure aimed to orient harvesting strategies at the artificial reef through the use of selective fishing gear so to allow optimal fishing yields and avoid disruption of the natural succession of artificial reefs and associated assemblages. Exploitation strategies should include different types of fishing gear to diversify the catches and exploit all the reef resources in order to avoid alterations in the equilibrium among the functional groups of fish and macroinvertebrates inhabiting the reef. Gear restrictions have been successfully adopted to manage artificial reefs in the United States (Mcgurrin, 1989; National Marine Fisheries Service, 1990). Bag (possession) and size limits are an extensively used management tool in Australia to regulate the harvest of recreational fishers (line and spear) on natural rocky reefs and artificial reefs. The measures are regularly reviewed based on stock assessments (McPhee, 2008).

3) Temporal closure: it can be adopted to avoid the exploitation of artificial reef resources in particular seasons of the year, for example to favour the reproduction and/or the early growth of juveniles at the reef, but this measure may increase congestion and overexploitation in the remaining periods.

4) Temporal segregation of users: it is aiming at separating user groups allocating specific periods of time when each group is permitted access. Times may be chosen on the basis of various factors such as stock availability, weather conditions, market prices, etc. In this way, the different user groups can continue to use the artificial reef without interacting between them. However, this management measure is easily enforceable only when the different user groups (e.g. recreational and professional fishers) are easily distinguishable and compliance resources permit. In addition, similar to closed seasons, the reef may increase congestion within user groups because access opportunities for each of them are compressed into shorter time periods.

5) Spatial segregation of users: it consists in creating separate artificial reef sites for each user group. Nevertheless, creating and maintaining multiple artificial reefs is much more expensive than other control options and can actually increase the likelihood of conflict if perception of better catch rates on one reef over another is reported, with fishers moving without consent onto another sectors reef.

The first four options are applicable where only one reef habitat exists, while all five strategies are feasible in multiple reef site environments. Stock effects can be reduced by regulating harvesting. This can be attained by establishing selective access control, setting catch limits (size and number), limiting fishing gear and selectivity, and setting temporal catch limits (temporal closure for fishing). Congestion effects can be reduced by selective access controls, gear restrictions and temporal or spatial segregation of users.

However, no single management control can be optimal for all situations and the choice of one or more options must be based on an evaluation to determine the nature of the conflicts and the effectiveness of the management options adopted. In this case, the involvement of fishers (small-scale or recreational fishers) and/or recreational divers, as well as research in the artificial reef management, is fundamental. Based on the results of biological monitoring and on the feedback from the socio-economic data collection, it will be possible to evaluate, at regular time intervals, the effectiveness of the management measures in place and to reformulate them, if necessary, following a flexible, adaptive approach.

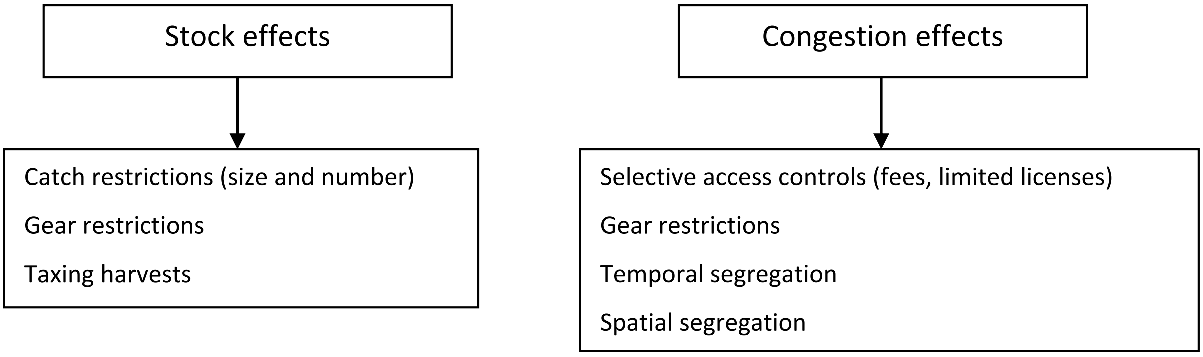


Figure 25: Habitat management controls to reduce users conflicts (modified from Samples, 1989).

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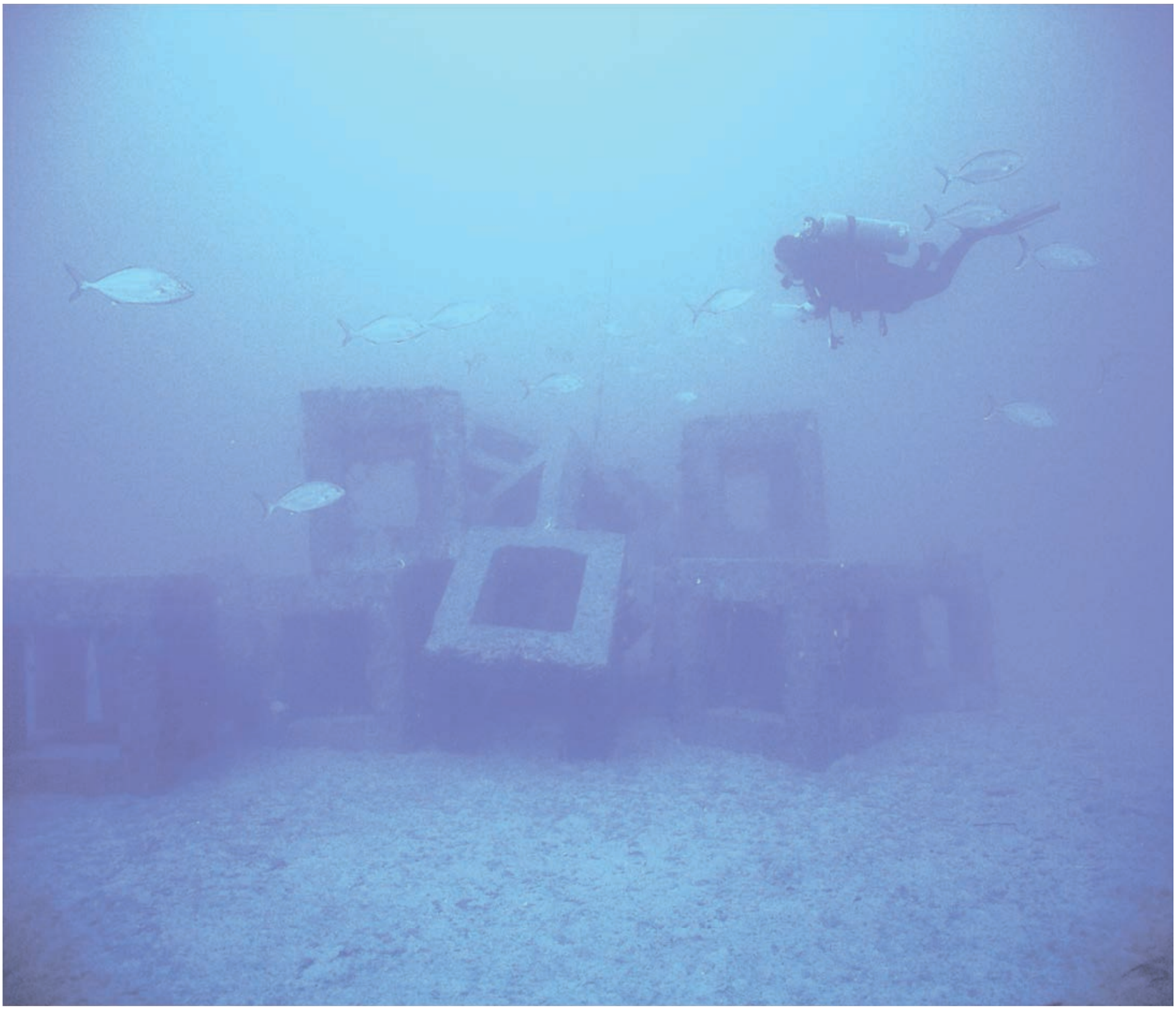
Artificial reefs have been used for a long time around the world and have served many purposes ranging from habitat restoration, fish stock enhancement and fisheries management to research and recreation. At present, fish stock enhancement and fisheries management are the main reasons driving reef construction in the Mediterranean Sea, while habitat restoration is the main purpose for their use in the Black Sea. The increasing interest for artificial reefs has given rise to several concerns regarding their possible negative impacts, due to the use of unsuitable materials and to waste dumping. Consequently, the need emerged over the past fifteen years to develop guidelines in order to support managers and scientists in the use of artificial reefs in European seas. Based on such existing guidelines, this document aims to further provide up-to-date information and guidance regarding specific management practices for the planning, siting, construction and anchoring of artificial reefs in the Mediterranean and the Black Sea and for monitoring their effectiveness from an ecological and socio-economic point of view. After providing an overview of existing definitions and legislations relating to the deployment of artificial reefs, this document illustrates the main aspects related to the different steps involved in the planning, siting and construction phases. A detailed presentation of the specific types and purposes of artificial reefs follows, with a description of their possible impacts and of existing methodologies to monitor and assess their effectiveness. Finally, these guidelines give insights about the socio-economic effects of artificial reefs and control, surveillance and maintenance issues.



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