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Practical Guidelines for Artificial Reefs in the Mediterranean and Black Sea

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PRACTICAL GUIDELINES FOR ARTIFICIAL REEFS IN THE MEDITERRANEAN AND BLACK SEA

FINAL DRAFT BEFORE EDITING

GFCM Workshop on Artificial Reefs in the Mediterranean and Black Sea (27 September 2013, Izmir, Turkey)
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1. INTRODUCTION

Artificial reefs historically have been used around the world to attract fish and facilitate their capture for human consumption. There is evidence that in the Mediterranean Sea the first artificial reefs were inadvertently created in 1500s. At that time, the rocks used to anchor the 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 fishermen between the tuna fishing seasons (Riggio et al., 2000). Historically, it is likely that similar practices were employed by artisanal fishermen across the world (Simard, 1995).

The modern concept of "artificial reef" was born in Japan in the 20th century after WWII and was adopted in the Mediterranean sea in second half of 1900s. To date, around 300 artificial reefs have been deployed in the Mediterranean and Black Seas. The main purposes for these deployments are to enhance fisheries and improve fisheries management.

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

In 2009, FAO General Fisheries Commission for the Mediterranean (GFCM) initiated debate on the use of artificial reefs in the Mediterranean and Black Seas, especially to enhance and manage fisheries and fishing resources (GFCM, 2010). This issue has been addressed during the annual meetings of the Sub-Committee on the Marine Environment and Ecosystem (SCMEE) that led to an *ad hoc* workshop in January 2011 (GFCM, 2011, 2012). Acknowledging the increasing interest of several Mediterranean countries towards artificial reefs, one conclusion of the workshop was that updated guidelines to support potential artificial reef developers were needed to establish and monitor artificial reefs in the coastal waters of the Mediterranean and Black Seas.

It is the goal of this document to provide the best and most generally accepted guidelines to give direction to management practices for artificial reef planning, siting, construction, anchoring and monitoring in the Mediterranean and Black Seas. These guidelines will provide resource users, managers and planners with essential information and guidance on the most effective methods for enhancing and protecting natural resources as well as improving fisheries and aquaculture opportunities.

The objectives of these Guidelines are:

- to update the information reported in the previously prepared guidelines;
- to assist the countries in the planning and deployment of artificial reefs on the basis of scientific criteria;
- to avoid pollution or degradation of the aquatic ecosystem due to the deployment of unsuitable materials as well as dumping of waste;
- to prevent negative impacts due to the deployment of artificial reefs;
- to provide information on the different scopes and types of artificial reefs, as well as on their potential effects;
- to provide technical information on the deployment, monitoring, on-going management and socio-economic effects of artificial reefs.

The first chapter provides a definition of “artificial reef”, a list of the reasons for which artificial reefs are usually constructed and the technical terms that have been used within the document and that should be used when referring to artificial reefs to avoid confusion. The subsequent chapters address planning, siting, materials, design and placement, including several examples of artificial reef construction in the Mediterranean Sea as well as in other areas, identify possible negative impacts, facilitate the standardization of monitoring methodologies, and suggest appropriate management.

1.1. DEFINITION OF ARTIFICIAL REEF

For the purposes of these Guidelines, the following definition has been adopted to promote a common understanding of the term, and to serve as standard definition. The definition has been derived from the *UNEP-MAP Guidelines for the Placement at Sea of Matter for Purpose other than mere Disposal (Construction of Artificial Reef)* (2005), the *London Convention and Protocol / UNEP Guidelines for the placement of Artificial Reefs* (2009), the *OSPAR Commission - Assessment of construction or placement of artificial reefs* (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

The artificial reefs can be considered as interventions of engineering technology to: recover and/or improve the natural habitats, increase productivity and manage aquatic resources.
In this context, artificial reefs are used in coastal waters worldwide for many applications, 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 to manage the life cycles of fish and connectivity.

The objectives for deploying artificial reefs 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 regarding 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.
For the purpose of this document the term “structure” refers to a module or a reef set.

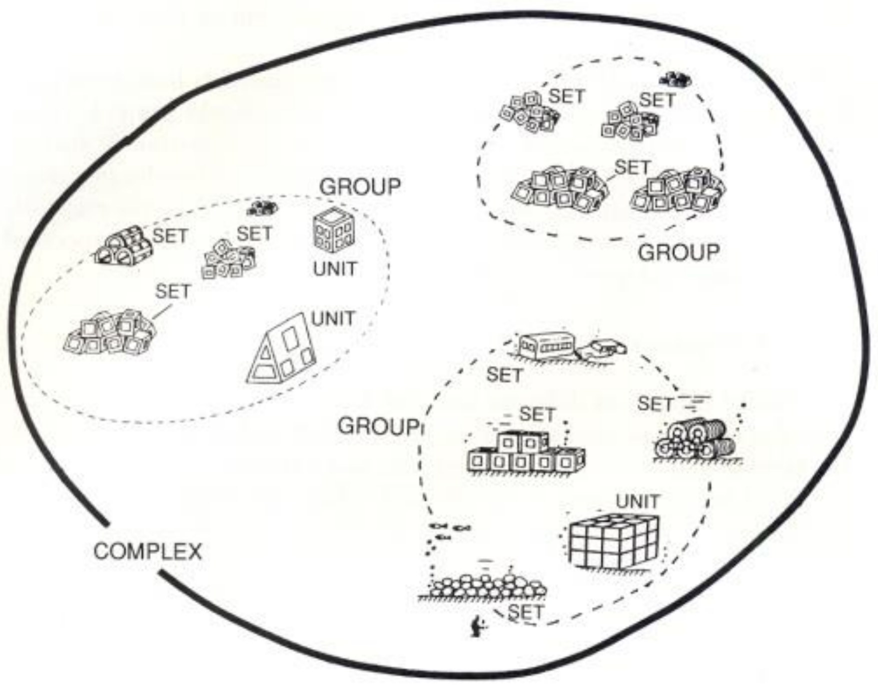

Fig. 1 – Hierarchy of the different components of an artificial reef (from Grove and Sonu, 1983).

2. INTERNATIONAL LEGISLATION FOR ARTIFICIAL REEF DEPLOYMENT

Artificial reef deployment in the Mediterranean and Black Seas falls under several international regulations concerning the protection of the sea against pollution due to dumping of unsuitable materials.

London Convention

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention, 1972), entered into force in 1975, is one of the oldest worldwide conventions to protect the marine environment from the human activities. In 1996 the Protocol of the London Convention replaced the 1972 Convention. The Art. 4 of this Protocol states 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.

In 2006, the Protocol entered into enforcement. 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; http://www.imo.org/blast/blastDataHelper.asp?data_id=25688&filename=London_convention_UNEP_Low-res-ArtificialReefs.pdf).

Mediterranean Action Plan and Barcelona Convention

The Mediterranean Action Plan (UNEP-MAP, 1975) is a regional cooperative effort drafted in 1975. MAP involved the European Community and 21 countries bordering the Mediterranean Sea. The objective of MAP was to protect the marine and coastal environment through regional and national plans to achieve sustainable development. This Plan led to the adoption of the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention, 1976) which entered in force in February 1978. The Barcelona Convention was revised in June 1995 as the "Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean". The main objectives of this Convention were:

- 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.

Seven Protocols have been added to the Barcelona Convention:

- Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by

Dumping from Ships and Aircraft (Dumping Protocol); adopted in Barcelona, Spain, on 16 February 1976, in force 12 February 1978; revised in Barcelona, 9-10 June 1995;
- Protocol Concerning Cooperation in Combating Pollution of the Mediterranean Sea by Oil and other Harmful Substances in Cases of Emergency (Emergency Protocol); adopted in Barcelona, Spain, on 16 February 1976, in force since 12 February 1978;
- Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources (LBS Protocol); adopted in Athens, Greece, on 17 May 1980, in force since 17 June 1983; amended in Syracuse, Italy, 6-7 March 1996;
- Protocol Concerning Mediterranean Specially Protected Areas (SPA Protocol); adopted in Geneva Switzerland, on 2 April 1982, in force since 1986; revised in Barcelona, Spain on 9-10 June 1995;
- Protocol for the Protection of the Mediterranean Sea against Pollution Resulting from Exploration and Exploitation of the Continental Shelf and the Seabed and its Subsoil (Offshore Protocol); adopted in Madrid, Spain, 13-14 October 1994;
- Protocol on the Prevention of Pollution of the Mediterranean Sea by Transboundary Movements of Hazardous Wastes and their Disposal (Hazardous Wastes Protocol); adopted in Izmir, Turkey, 30 September - 1 October 1996;
- Protocol on Integrated Coastal Zone Management (ICZM), adopted in Madrid, Spain, 21 January 2008.

Based on the Mediterranean Action Plan and the Barcelona Convention, the following guidelines were subsequently developed:
- Guidelines for the placement at sea of materials for purposes other than the mere disposal (construction of artificial reefs) (UNEP-MAP, 2005; http://195.97.36.231/acrobatfiles/05WG270_10_Eng.pdf);
- Technical guidelines for the environmentally sound management of the full and partial dismantling of ships (Secretariat of the Basel Convention, 2003; http://www.basel.int/meetings/sbc/workdoc/techgships-e.pdf).

Bucharest Convention

The Convention on the protection of the Black Sea against pollution (Bucharest Convention) was signed in 1992 with the aim of protecting the marine environment of the Black sea and preserving its living resources. This Convention entered in force in 1994. Three Protocols have been added to the Bucharest Convention:
- Protocol on Protection of the Black Sea Marine Environment Against Pollution from Land-based Sources; adopted 1992, in force since 1994;
- Protocol on Cooperation in Combating Pollution of the Black Sea Marine Environment by Oil and other Harmful Substances in Emergency Situations; adopted 1992, in force since 1994;
- Protocol on the Protection of the Black Sea Marine Environment Against Pollution by Dumping; adopted 1992, in force since 1994.

The last one is also related to artificial reefs (art. 8).

All the Conventions and Protocols cited above can be found at the following website: http://www.unep.ch/regionalseas/main/hconlist.html#med

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 all the life of the reef.
A crucial factor of artificial reef success is the effective cooperation between numerous maritime actors, such as managers, planners, engineering offices, local and regional authorities, fishermen, divers and all stakeholders concerned by the coastal management. When all interested parties concerned with the artificial reef are involved and kept informed of the status and activities about the reef construction, management and use, then these parties will be more likely to offer guidance and assistance (see chapter 9).

3.1. PRE-CONSTRUCTION PHASE

This phase includes all actions to be undertaken prior to installation of an artificial reef; from the decision of constructing the reef to the submission of the reef plan to the competent authorities.
The first step in planning an artificial reef is to identify the broader goal/s for the construction of the reef (e.g., to enhance recreational fisheries or manage professional fisheries) and to evaluate the ecosystem where the artificial reef should be deployed and how that environment will be affected by the immersion of new substrates. Therefore, the questions to be answered before making a commitment to further planning and development are:
a) Is the concept of the reef realistic? This question is aimed to evaluate if the idea to construct an artificial reef is valid in a particular area, before making a commitment.
b) How will the new reef and natural ecosystem interact? It is essential that the influence of an artificial reef upon the sea floor be understood before construction, in terms of how the natural habitat may be modified and how ecological processes may be affected by the new substrates.
Concurrently, it is necessary to evaluate the local social and economic situation and involve the potential users of the artificial reef to consider their opinions on the project.
Once the above questions have been addressed, more specific objectives should be defined (e.g., increase to a certain level the income of the local fisheries). Once the broader goals and specific objectives of the artificial reef are defined, it is necessary to calculate the investments and the expected ecological and socio-economic returns. With this information, it will be possible to verify the performance of the artificial reef over time.
This step also helps to evaluate whether the choice of constructing an artificial reef is actually more effective in respect to other solutions.
Once the specific objectives have been established and a preliminary cost analysis has been performed, it is possible to identify definitively the reef site and design the artificial reef.
In the selection of the reef site, it is necessary to take into account the physical features of the proposed site (depth, sediment grain-size, currents, waves, etc.), the life history of the target species (i.e., distribution, reproduction, feeding, etc.), and the specific location of the site in respect to the purposes of the reef (e.g., if an artificial reef is constructed to enhance local small-scale fisheries it should be located close to the mooring sites).
The choice of materials must be made concert with international and national legislation to avoid dumping and pollution in the marine environment. Additionally, the reef design must be conducted by experts in the field and based on ecological and technical specifications relative to the reef purposes and setting.
Finally, the reef plan has to be submitted for permission to the responsible national and/or local authorities which will establish liability, maintenance and monitoring of the artificial reef.

3.2. CONSTRUCTION PHASE

This phase includes all activities concerning the construction of the artificial reef structures and their deployment at sea.
In general, attention should be paid in identifying the construction area, where the reef material can be stored. 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 through buoys around the deployment site to avoid risks to leisure boats, divers, etc. during construction. The activity of transporting of the reef material from the staging area to the deployment site may restrict manoeuvrability representing potential hazard to navigation. Consequently, it is prudent to notify to the marine authorities the 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 the sites through GPS and mark them with temporary marker buoys.
Once the deployment operations have been completed, the correct position of the reef structures should be verified through direct observation by scuba divers or indirect surveys with side scan sonar or multibeam echosounder.

3.3. POST-CONSTRUCTION PHASE

After the artificial reef construction, the subsequent question is: How can the reef be managed and used in a sustainable way? This question is aimed at identifying management options to optimize the benefits to all users of the reef and to reduce conflicts among them. This issue may not be particularly relevant when an artificial reef is constructed by private entities who will have the ownership of the reef site. However, this is issue is fundamental in the case of artificial reefs sponsored by national, regional or local authorities for the local communities (see chapter 11).
Another important issue is to determine the effectiveness of the artificial reef. A scientifically valid monitoring program must be developed and “success criteria” must be established. Monitoring will enable the project sponsors to gain evidence concerning the ecological and socio-economic performance of the reef toward meeting 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 in selecting a site for artificial reef construction.

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

Physical and chemical variables as well as ecological features should be taken into account in the identification of the artificial reef location.

Physical and chemical variables include sediment type, depth/bathymetry, currents, waves, sedimentation rate, water turbidity, salinity, nutrients.

The stability of a reef is related to its structural characteristics (i.e., weight, density and design of modules), 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 leading to 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 strong sedimentation (such as those areas close to river mouths), 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, in turn, affect the fish assemblage that will inhabit the reef. 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 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 usually represent the most important pioneer organisms just after the immersion of the artificial structures but later algae tend to become dominant. Mussels are usually absent, while oysters may constitute a relevant component of the benthic assemblage. Instead, in eutrophic waters light is less important. Also in this case the 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 and which find a suitable habitat in the mussel byssum (e.g., errant polychaetes and amphipods).

Proximity of the deployment site to sources of pollution may lead to accumulation of contaminant in the organisms inhabiting the artificial reef.

The biological variables to be used to determine the right position of an artificial reef are: 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 sea grass meadows unless the reef is not realized 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 sea grass 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). Oppositely, 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 same structures will be colonized by different assemblages and at different rates when placed at various distances from similar habitats.
Also, life history, 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 should be taken into account especially in case of restoration and production artificial reefs.
Therefore, pre-deployment inspections should be conducted at the reef site to determine the sediment type, grain size and thickness, depth, occurrence of natural hard substrates and /or sea grass meadow, intensity and direction of currents and waves and valuable information of the biology and ecology of target species should be collected. This information will help refine the reef site selection and identify the materials and modules more suitable to assure stability and effectiveness of the reef over time.
Siting of an artificial reef must also take the purposes of the project and the expected users into consideration. 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 a reef might not be fully used if it is placed too far from the mooring sites. Oppositely, if fisheries or diving enhancement is 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 for divers.
Finally, to avoid conflicts among users, the placement decisions regarding artificial reefs should consider already existing or anticipated activities in the area. These activities include: navigation, recreation, fishing, aquaculture, and Marine Protected Areas. This consideration is especially important in the case of large-scale artificial reefs.
In general, prior to artificial reef deployment, the different users of the area and potential stakeholders of the reef should be adequately informed on the reef project and their viewpoints should be considered in the selection of the reef site.

4.2. MATERIALS

The material used can affect the colonization of the 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 to avoid pollution and bioaccumulation of contaminants in the environment and in the aquatic organisms.
The choice of the material should also consider the resistance to the chemical and physical forces in constant action in the marine waters, the time-life, and the suitability for colonization by benthic communities.
With regard to stability, a general rule is that the weight of the material used for the construction of the reef units should be at least double than that of the specific gravity of

seawater or, alternatively, that the structure is actually anchored to the seabed (OSPAR, 1999).
For durability, the material should assure a minimum life time of 30 years; for functionality, the material be capable of being colonized by benthic organisms based on field verification conducted for a minimum of 1 year. Lastly, for economic reasons, the materials should be cost-effective (Grove et al., 1991).
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 or deployed in chaotic piles or assembled inside frames 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 been also utilised. These materials facilitate the pre-fabrication of specifically designed modules prior to water transport to the deployment site.
Ecological consideration should also be given as some materials can be selective towards benthic organisms. For example, a greater abundance of benthic species was recorded on concrete and plywood than on fiberglass or aluminium (Anderson and Underwood, 1994). Bombace et al. (1997) 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 with advantages and disadvantages is reported in Table 1.

4.3. TYPES OF REEF STRUCTURES

The types 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 of 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).
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 Black Seas, the use of these materials is strictly regulated by national laws according to the international Conventions and Protocols to avoid dumping of waste at sea. It is important to underline the need to cleaning up these structures prior deployment 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).
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 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 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 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).
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 the 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 are 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 with 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 keep 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. – Compatibility with the marine environment.	– Shells must be generally purchased. – Shell is a small material and, consequently, has a tendency to be silted especially if the substrate is sandy or muddy.
	Rock	– Compatibility with the marine environment. – Quarry rock is 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 it is required the use of heavy equipment. – 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 it needs for heavy equipment to be handled. – 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.
	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 shape and dimension.	– Not all ash materials are suitable; 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 programs.

Table 1 - Continue.

Materials	Advantages	Disadvantages

Artificial materials	Electrodeposition	– The material 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 that a platform 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 demolition waste), allows a wide choice. – The use of recycled material can reduce 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.
	Vehicle tires	– Vehicle tires are lightweight and easy to handle, particularly when un-ballasted. – 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 un-ballasted 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, 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 in order 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.

Table 1 - Continue.

Materials		Advantages	Disadvantages
	Vessels	– Vessels make interesting diving locations for divers. Vessels are also regularly utilized as angling sites by recreational fishermen and the charter fishing industry.	– 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).

		– 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 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 programs.	– 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: 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.). – Removal of hazardous materials, pollutants, and other material 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, number of compartments, void spaces, and overall complexity increases. – 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 utilized 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.

Table 1 - Continue.

Materials		Advantages	Disadvantages
	Steel-hulled vessels	– More resistant in respect 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	– Discarded fiberglass boats are readily available and cheap.	– The fiberglass vessels have to be cleaned and sufficiently ballasted for sinking.

	vessels		– This material may have little long-term value as reef habitat due to instability, lack of durability or the 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 water 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 benefit 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 labor-intensive. – Vehicle bodies are not durable, lasting for one to five years in the marine environment. Considering that about one year is required 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 at about year four, vehicle bodies may have about three years of useful life as an artificial reef. – Vehicle bodies are not stable, and likely can 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 been 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

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 the reef 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.

5. FUNCTION-SPECIFIC CRITERIA

Here is provided a more detailed information on the criteria to be used in the construction of artificial reefs relative 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 dissuasion tool for fisheries (i.e. illegal trawling) and as protection tool for the marine resources, environment and other legitimate activities.
This application is frequently employed to protect habitats of ecological interest or important 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 gears.
Some protection artificial reefs can be used to protect other structures like cables, oil or waste water pipelines and thereby preventing pollution damages.

5.1.2. DESIGN AND MATERIAL

Protection artificial reefs should be specifically designed to withstand the power of fishing vessels in the 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 avoiding to be moved 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).

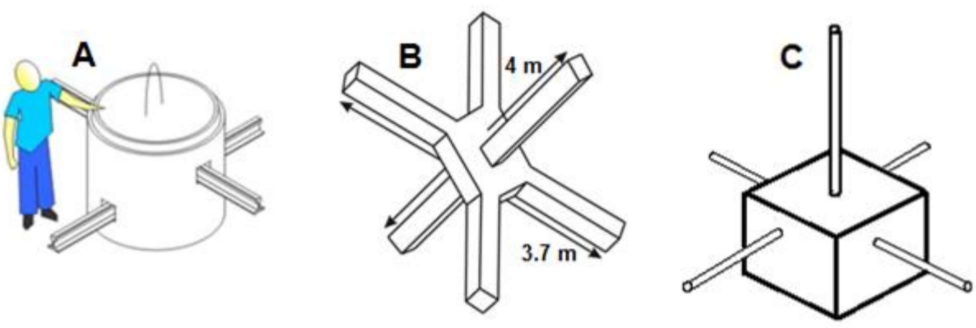

Fig. 2 - Examples of protection units. a) Spain; b) France; c) Tunisia (modified and courtesy of J.J. Goutayer Garcia, E. Charbonnel, and N. Haddad).

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

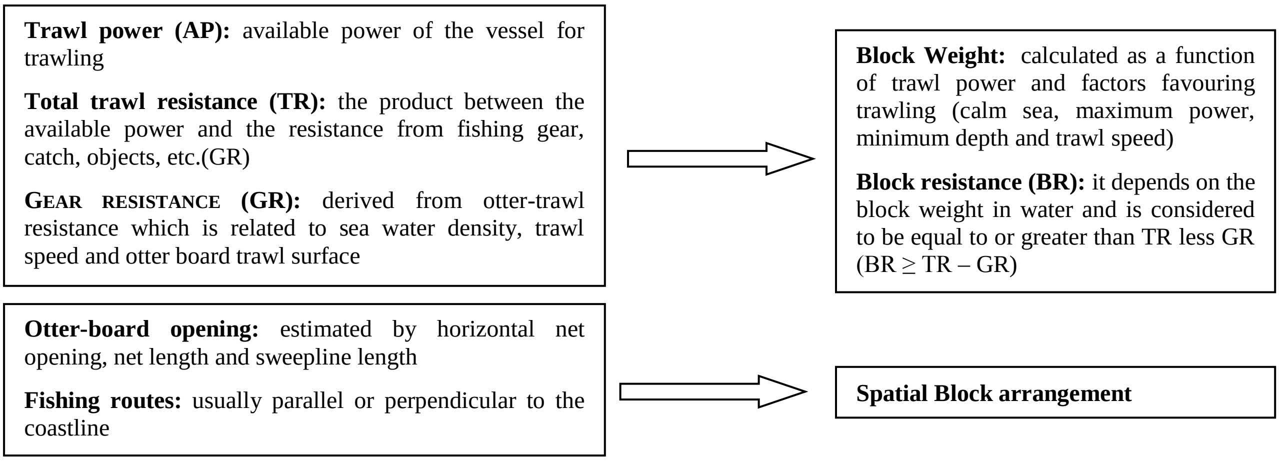

Fig. 3 - Variables to be considered when designing anti-trawling reef units. (modified from Ramos-Esplá et al., 2000)

5.1.3. SITING

Due to the extension of these artificial reefs planning the location of the units on the seabed requires knowledge of some features of the seafloor and the distribution of natural habitats or man-made structures (pipeline, cables, etc.) to protect them, avoid damages and prevent negative impacts.
It is also essential to know the fishing routes in the area to place the modules along lines perpendicular to the routes. The distances between modules should be less than the otter-board / dredge openings, hence of 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 effectiveness of the artificial reef and costs. Usually, these modules are placed alternate along two or three paralleled lines.
When protection artificial reefs are deployed to create suitable grounds for selective small-scale fisheries and protect the resources from other less-selective fishing activities, the reef units should be placed in such way to allow the use of set gears 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.

5.1.4. PRACTICAL APPLICATIONS

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

5.1.4.1 Spain

The development of artificial reefs in Spain are motivated by the necessity of protecting 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 of Spanish fisheries policy. Along the Mediterranean coast, the depth of deployment ranges from 10 to 35 m - sometimes to a depth of 50 m. The protection artificial reef projects developed in Spain have tried to optimize the design of units to improve their function and optimize both the number of units and also their arrangement on the seafloor (fig. 4). The goal is to protect as much area as possible minimizing costs and habitat modifications. The cost reduction is also obtained by the employment of maritime conventional means for the installation without intervention of divers.

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

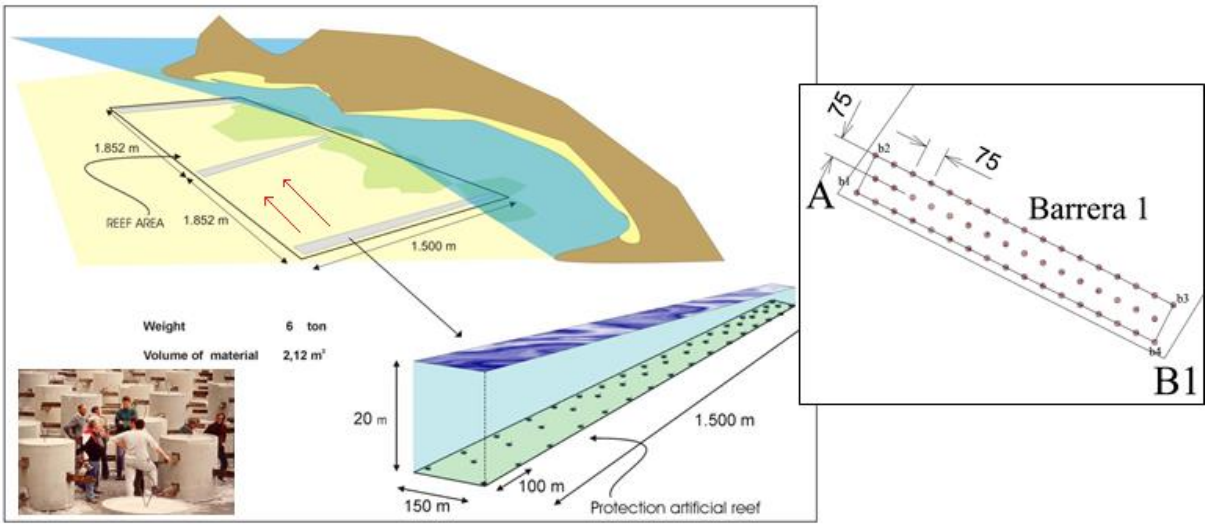

Fig. 4 – Spain: scheme of a protection artificial reef. The protection units are placed along three lines perpendicular to navigations routes of trawlers (red arrows) to protect the *Posidonia* and *Cymodocea* beds (green area) inshore and leave space for artisanal fishing activities (modified from and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

5.2. PRODUCTION ARTIFICIAL REEFS

5.2.1. OBJECTIVES

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

When opportunely designed, artificial reefs may increase the biomass, hence increase 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 reefs can be also 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 the production artificial reefs include:
- recovery of depleted stocks, by increasing survival of juveniles providing 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 the need of reducing fishing effort of trawling in an area, production artificial reefs can be used in negotiation to create new fishing grounds allowing fishermen to shift towards more selective fishing activities;
- development of extensive aquaculture of algae and molluscs, providing suitable substrates for settlement.

5.2.2. Design and Material

The modules generally used for production artificial reefs should be alveolar, of various shapes, and should have an appropriate amount of surface area and niches of various shape and size available for the establishment of settling organisms. Differently from the protection reef units, production units have usually more volume in relation to their weight, creating the tree-dimensional complexity and developing surfaces which can be colonised by sessile organisms (fig. 5). Rough surface texture enhances benthic settlement providing refuge and supporting greater diversity (Harlin and Lindbergh, 1977; Hixon and Brostoff, 1985; Beserra Azevedo, et al. 2006). Consequently it also affects the fish assemblage attracting fish grazing.

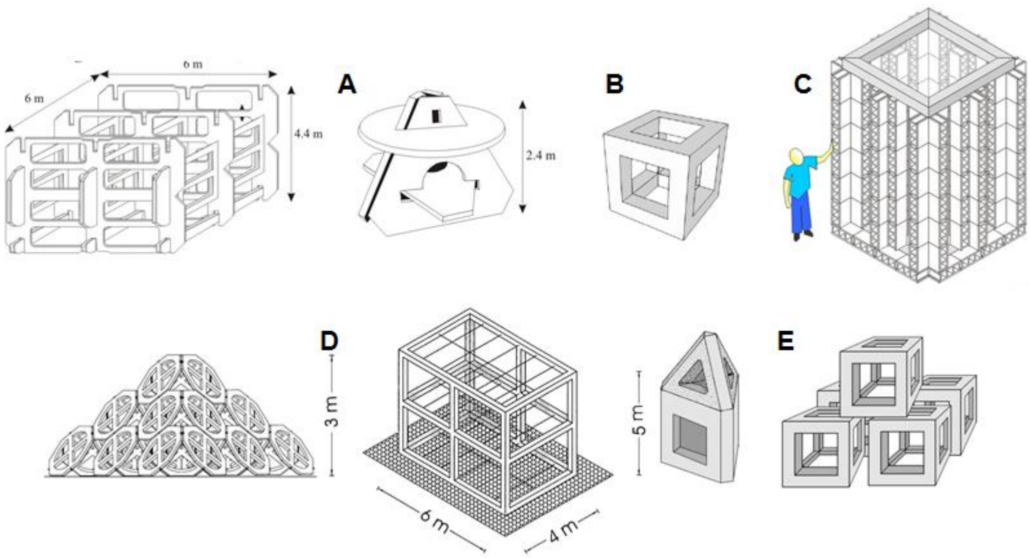

Fig. 5 – Examples of production artificial reef modules (A: France, B: Tunisia, C: Spain, D: Italy, E: Turkey) (modified and courtesy of E. Charbonnel, N. Haddad, J.J. Goutayer Garcia, CNR-ISMAR Ancona, and A. Lök).

Besides food availability, composition, diversity and abundance of the reef fishes are strongly affected 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. Consequently, the artificial reefs can host more small and medium-sized than large organisms which tend to migrate outside. Therefore, the placement of large-holed reef units (especially in marine protected areas) 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 the artificial reef structures are:

- independent of the size and the life stage, generally fish prefer cavities where there is light and with many openings to enable them escaping from predators;
- 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.

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 to identify those that are more appropriate as targets for artificial reef deployment and that 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, 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, labrids);

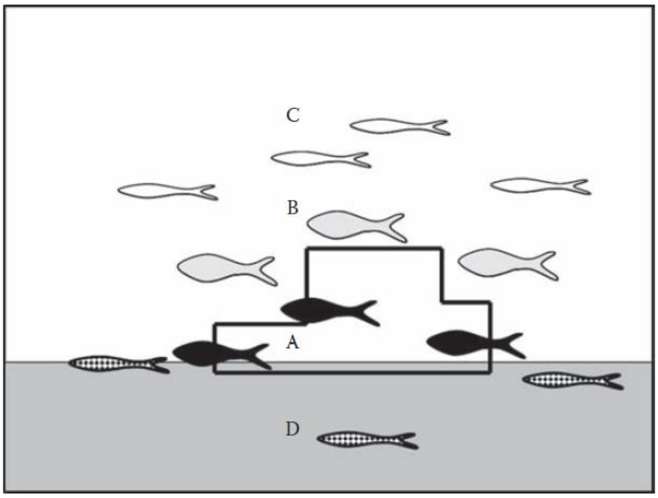

Fig. 6 – Classification of fish according to their position relative to the artificial reef (from Bortone, 2011).

- *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 linked to them by vision and sounds (e.g., mugilids, lamberjacks, 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).

In fig. 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 characterised 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. Type A species, which have a strong production relationship (e.g., spiny lobster or octopus) might gain a significant advantage from artificial reef deployments, while type B fish will get benefit from artificial reefs depending on their life history strategies.

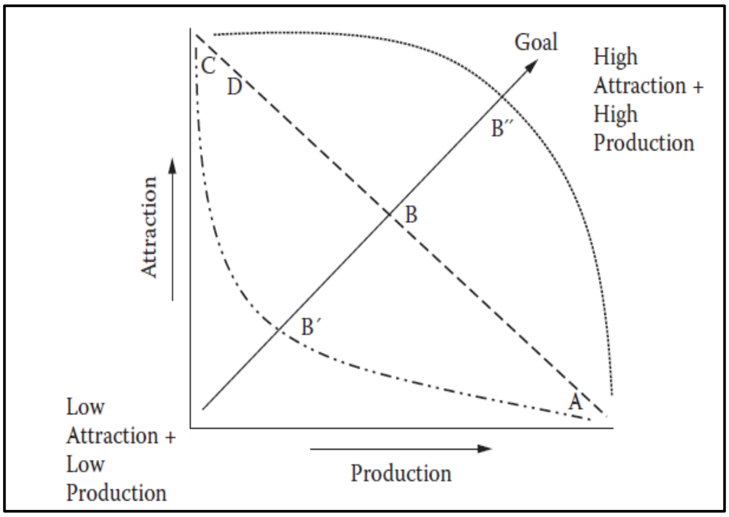

Fig. 7 – Relationship of A, B, C, and D-type artificial reef species relative to attraction and production features of artificial reefs. B′ and B″ indicate the position of B-type species with different life history strategies (from Bortone, 2011).

For attracting Type A organisms, the artificial reef structures do not need to extend along the water column but have to be provided with internal spaces matching with the size of the target species, while for Type B fish the holes should be larger and the artificial reef structures must reach at least a height of 2 m. For aggregating Type C species the artificial reef should extend along the water column and the 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.

It derives that 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 the reef structures within an artificial reef may affect its influence on fish. Great distances between the reef units / reef sets may increase the total bulk volume of

the artificial reef but its effects on fish may be reduced if the structures are placed too widely from each other.
In general, the criterion to be applied in positioning the 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 each other when included inside a reef complex (fig. 8).

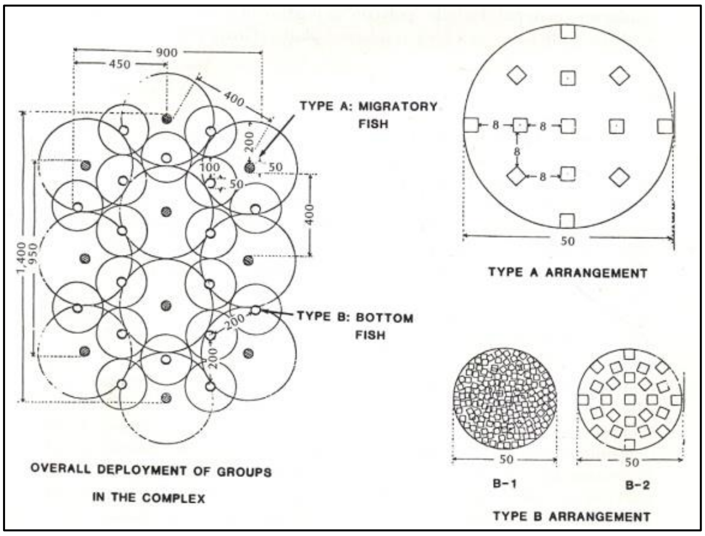

Fig. 8 – Spatial arrangement of reef units/reef sets in a reef complex (from Grove and Sonu, 1985).

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 realized for enhancing and managing the local fisheries, shifting the fishing effort helps to 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 allowing to reduce travel and search time, save fuel and increase fishermen’s safety.
When artificial reefs are constructed for localising and managing the entire life-cycle of migratory fish, different reefs, each matching with the ecological requirements of a certain life-stage of the target species, should be deployed along the migratory route of the targeted species.

5.2.4. PRACTICAL APPLICATIONS

5.2.4.1 France

Among the 94,000 m^3 of artificial reefs existing in France, one third concerns the Marseille reef complex, the largest artificial reef deployed in the Mediterranean Sea with 27,300 m^3 on 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 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 increased by addition of several types of small filling materials (bags containing oysters shells, breeze blocks, octopus pots used for fishery) and floating immersed ropes. Piles of quarry blocks of variable sizes were also used, to reconstitutes natural rocky boulders.
The different modules were grouped in 6 reef groups of triangular shape (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 for optimizing a rapid colonization of the artificial reef (fig. 9).

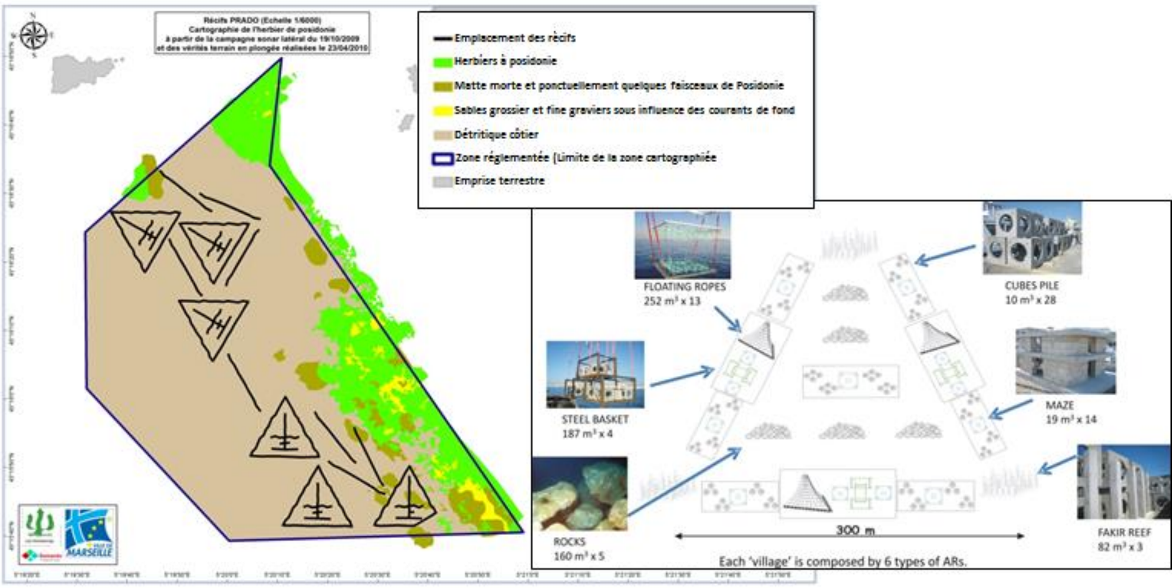

Fig. 9 – France: Marseille Prado artificial reef, the largest reef deployed in Mediterranean in 2007-2008; composed of six "villages" linked by 8 connections (above, in green: lower limit of *Posidonia* meadow). Each village has a triangular shape and constituted with 6 types of artificial reefs (below) (from Charbonnel *et al*., 2011).

5.2.4.2 Greece

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

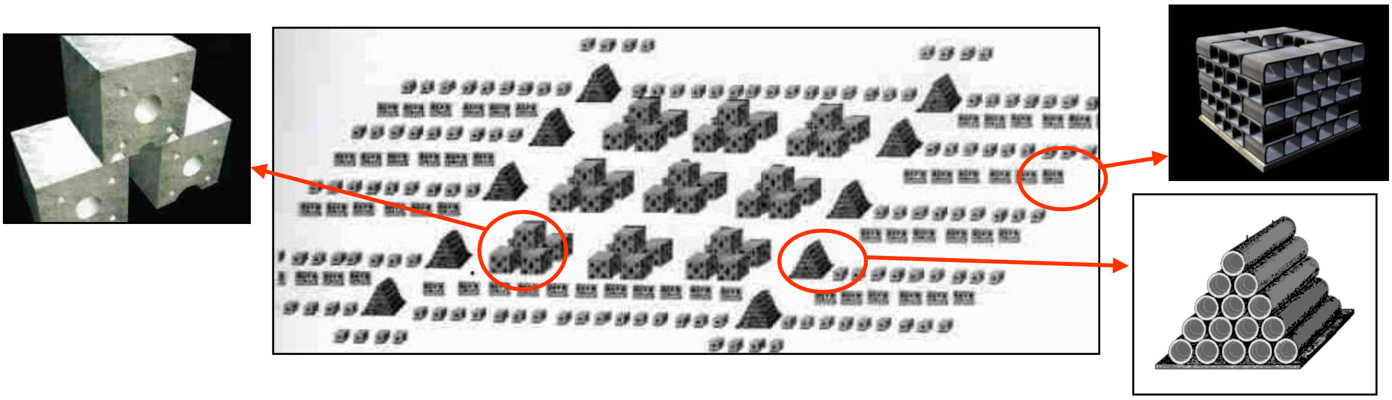

Fig. 10 - Greece. An artificial reef plan using four different types of modules in order to increase the reef complexity (modified from and courtesy of A. Kallianotis).

5.2.4.3 Turkey

Octopus species are habitat-dependent and of great economic interest. Despite a lack of specific information, data show that individual weight of octopus 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 spear fishermen. 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 provided with holes were employed and placed on the sea bottom.
The first results showed that octo-reefs are actually used by octopus (fig. 11). Hence, the next step will be to deploy this type of artificial reefs in a closed fishing area and in marine protected areas.

Fig. 11 – Turkey: production artificial reef units for octopus (courtesy of A. Lök).

5.2.4.4 Japan

Artificial reefs aimed to manage the life-cycle of migratory fish were constructed in a Bay of 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 allowed to confine the life-cycle of snapper into the bay, to considerably improve their survival, and their catches to be managed by the local fishing communities (Nakamura, 1985).

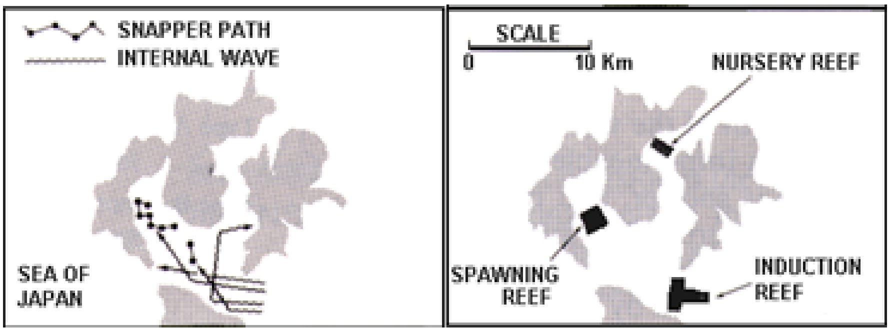

Fig. 12 - Deployment of artificial reefs aimed to manage the entire life-cycle of snapper (from Nakamura, 1985).

Similar applications could be adopted in the Mediterranean and Black Seas 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 growth. A restocking experiment conducted with juveniles sea bass (*Dicentrarchus labrax*; 15 cm TL) released at an artificial reef located at 11 m depth in the northern Adriatic Sea demonstrated that, just after release, the fish migrates inshore, especially close to estuarine areas. In the subsequent months, as they grew, 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 sea bass (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 MATERIAL

There is a tendency to deploy shipwrecks to accommodate the needs of users (divers and recreational fishermen). However, utilization of vessels as diver attractants has some associated level of risk that should be carefully evaluated in the choice of the vessel. High structure complexity and facility of penetration inside the wreck may increase the risk for a dive. Moreover, it is important that the vessels are deployed correctly, in vertical position, and in such way to assure their stability on the seabed.
Otherwise, to create an artificial reef site of ecological interest and able to sustain recreational

activities, the same approach should be applied as for the production artificial reefs.

5.3.3. SITING

These artificial reefs should be placed in areas easily accessible from the local harbours and/or from the beach, possible in a sheltered position so diving and recreational fishing are possible in poor weather conditions.
Water temperature, sea state, current velocity, depth, visibility, and distance from shore may all play an interactive role in impacting the challenge level/safety of divers.

5.3.4. PRACTICAL APPLICATIONS

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

5.3.4.1 Albania

The southern Albanian coastline hosts diverse and valuable marine habitats threatened by rapidly increasing coastal development and tourism. A diving survey conducted in the last decade indicated a great potential for diving tourism in 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 has been forecasted within the Pilot Fishery Development Project (Government of Albania & World Bank, 2006). Five decommissioned Albanian Navy vessels were purposely sunk in 2010 in Ksamil Bay with the support of the United States Naval Ship Grapple (fig. 13).

Fig. 13 – Albania: ship wrecks sunk as artificial reefs for diving in Ksamil Bay (http://www.albaniamarinecenter.org/pages/waittroc.html; http://www.travelblog.org)

5.3.4.2 Turkey

Bodrum peninsula (southern Aegean Sea) is one of the most important touristic and recreational diving area 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 of two old ships and one aircraft (fig. 14) as artificial reefs at South of Karaada (South of Bodrum peninsula) in 2007, 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.

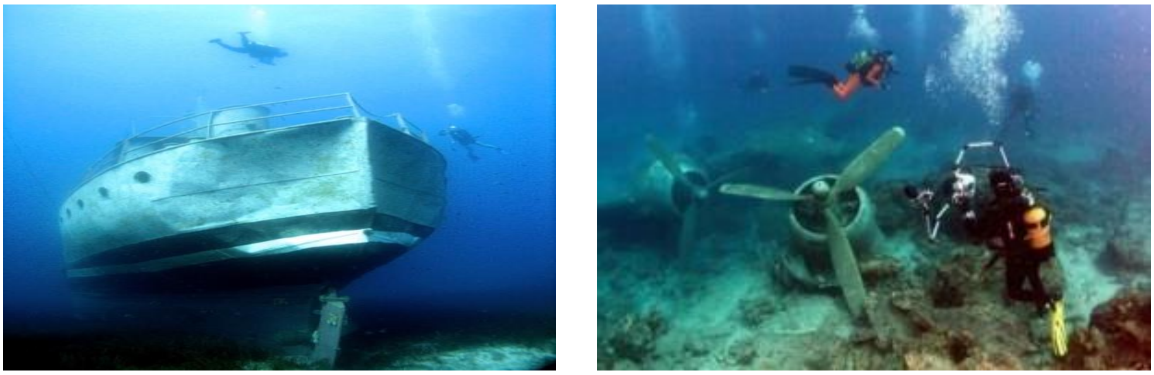

Fig. 14 – Turkey: a ship wreck and an aircraft sunked as artificial reefs at South of Karaada (courtesy of A. Lök).

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 not to create something that would not naturally exist in the environment.

Particular attention has 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 damaged through shipping accidents or at damaged sites used by tourist operators. However, the use of artificial reefs is recommended only to supplement damaged reef areas of a few square meters. Such methods are not considered viable or feasible for coral reef rehabilitation on the scale of square kilometres due to the potential damage that the installation operations can cause to adjacent coral reefs and associated ecosystems (ICRI, 2009).

Mitigation reefs should be created just after the habitat or the resources are impacted as delays can contribute to increase the ecological losses.

5.4.2. DESIGN

In this case, natural materials 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 transplantation of corals from the impacted areas to enhance the mitigation process.

5.4.3. PRACTICAL APPLICATIONS

5.4.3.1 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 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 to the EU community and designated as a Natura 2000 Site in accordance with the EU Habitats Directive. The project consisted of the immersion of around 60,000 m^3 of boulders of various sizes and weights (1-6 t; fig. 15).

Fig. 15 - 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. OBJECTIVES

To maximise the benefits from the construction of an artificial reef and reduce 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 each other. The most common application of multipurpose artificial reefs in the Mediterranean Sea joints together the functions of protection and production.

5.5.2. DESIGN

A multipurpose artificial reef will include modules of different type or, alternatively, reef units/reef sets adequately designed to achieve the functions of the reef. For example, an artificial reef for protection and production will include both units that act 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. 16). In this case mixed units are basically protection modules with some characteristics of production like small cavities or surfaces for the settlement of benthic organisms or eggs.

Similarly, a production and recreational artificial reef can include structures to increase the biomass and shipwrecks.

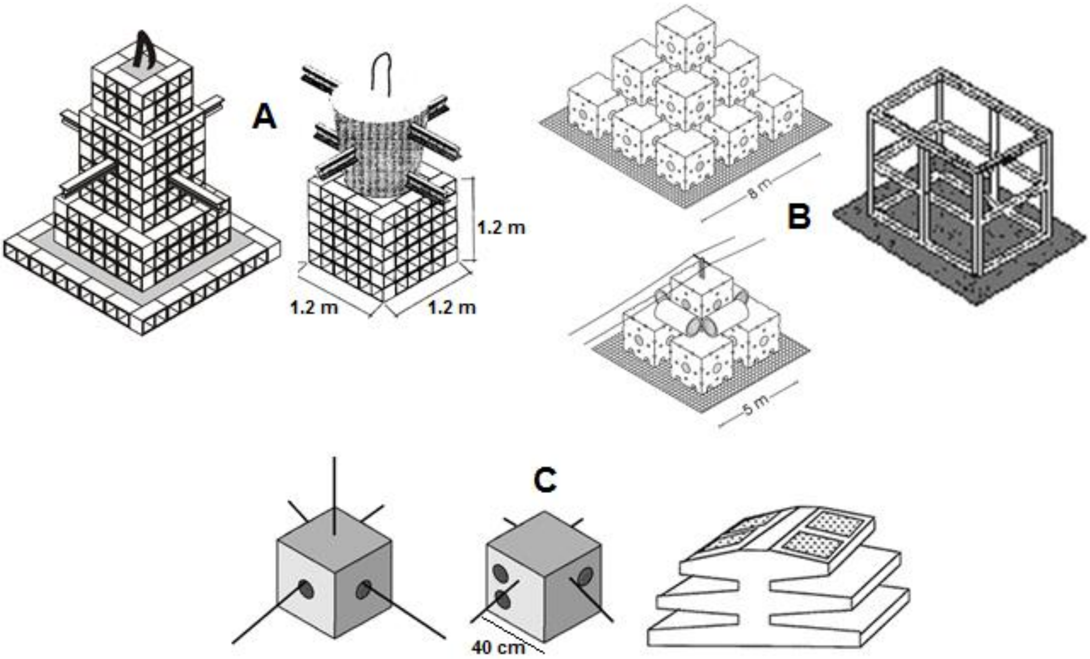

Fig. 16 – Examples of multipurpose artificial modules. A: Spain, B: Italy, C: Tunisia (modified and courtesy of J.J. Goutayer-Garcia, CNR-ISMAR Ancona, and N. Haddad).

5.5.3. SITING

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

5.5.4. PRACTICAL APPLICATIONS

Examples of multipurpose artificial reefs are common in Italy, Greece, Spain, and Tunisia.

5.5.4.1 Protection and production

Italy - Since the 1970s artificial reefs have been deployed along the Italian coastal areas to protect coastal habitats and fishing communities against illegal trawling as well as to enhance small-scale fisheries. Moreover, along the Adriatic Sea, where an important clam fishery (*Chamelea gallina*) operates with hydraulic dredges on the sandy-mud bottoms located in shallow water up to about 11-m depth, small-scale fisheries have conflicts both with illegal trawling for resources competition and damage to the set gears and with hydraulic dredges for space competition and, again, damages to the gears.
The strategy adopted to reduce these conflicts was to allocate space and resources by constructing 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: protection modules, b) production modules, and c) mixed modules.
Anti-trawling structures associated with production units or mixed modules (fig. 17) were employed (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 enter inside the prohibited area perpendicularly to the shoreline, these reefs consisted of rectangular zones, as longer as possible, placed horizontally in respect to the coast. The distances between modules were calculated on basis of otter-board openings (fig. 17). These artificial reefs led to a reduction in conflict between fishers as they created suitable areas where small-scale fishermen can carry out their seasonal activities on the basis of the eco-ethology of the different species inhabiting the reef, often joining co-operatives which manage the reef areas and their resources.

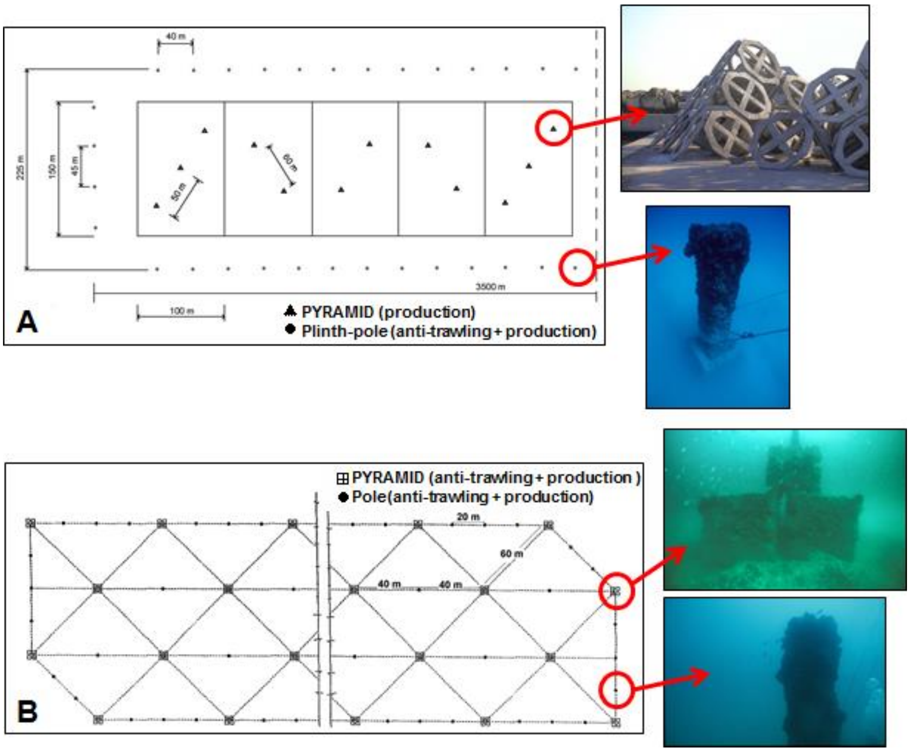

Fig. 17 – Italy: examples of multipurpose artificial reefs deployed along the coast of the northern and central Adriatic Sea (courtesy of CNR-ISMAR Ancona).

Spain - Similar strategies were adopted along the Spanish Mediterranean coast 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), improving marine communities, and preventing conflicts between fisheries. Also in this case, protection, production and mixed modules were used and displaced to prevent trawling regardless their course (fig. 18) (Moreno, 2000; Ramos-Esplá et al., 2000).

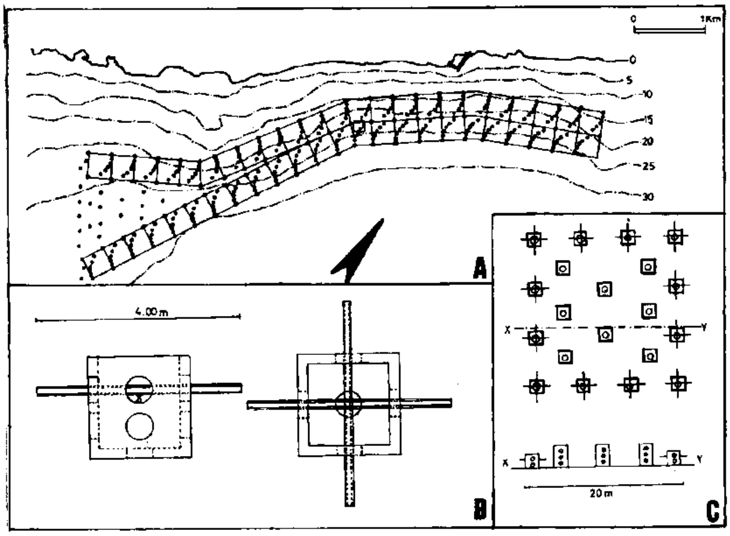

Fig. 18 – Spain: example of a protection and production artificial reef (El Campello) realised with anti-trawling and mixed modules: a) plan of the artificial reef; b) protection uit; c) attraction/concentration set and displacement of the units inside a reef set (from Ramos-Esplá et al., 2000).

Tunisia – In Tunisia there has been an increase in overfishing due to the introduction of large trawlers and the progressive decline of *Posidonia* meadows resulting from the illegal activity of small-sized trawlers in coastal areas. Over the past ten years these factors have led to a gradual decrease of demersal resources with consequent reduction in the income to small-scale fishers. Moreover, it has been estimated that around 90% of seagrass beds, representing important spawning and nursery areas for several coastal fishing resources, has disappeared in the Gulf of Gabes. To solve these problems, the Tunisian government has adopted a management policy in 2002 towards regulating fishing practices to maintain the equilibrium between fishing pressure and exploitable fishing resources. The program also included the adoption of active measures to protect and restore marine habitats on fishing grounds, enhance fishing resources and diversify the small-scale activities. One of the most relevant management measures was the construction of protection and production artificial reefs.

Most artificial reefs were simple concrete blocks provided 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 fishermen. More recently, a new design has been adopted which allowed the construction of more complicated multipurpose artificial reefs for protection and production. These new artificial reefs include modules for production of algae having also protection function (M1; fig. 19), production modules of different dimensions (M2 and M3; fig. 19), protection modules (M4; fig. 19), and modules for reproduction and nursery (M5; fig. 19).

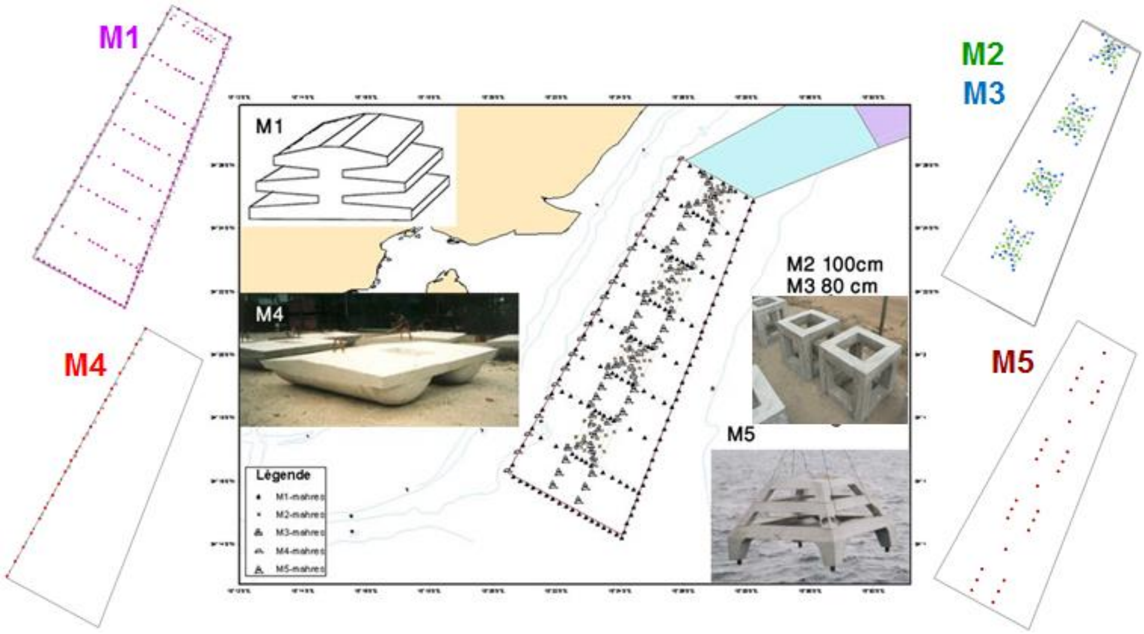

Fig 19 – Tunisia: plan of the multipurpose artificial reef Mahrés 3 (Gulf of Gabes) (modified and courtesy of N. Haddad).

5.5.4.2 Protection, production and extensive aquaculture

Italy **-** Artificial reefs were deployed within the coastal area of the northern Adriatic Sea by local small-scale fishermen associations to improve their activity by creating suitable habitats for reef-dwelling fish and macroinvertebrates and favouring the development of mussel wild populations. In this case the reef sets were composed by two types of mixed modules: a) protection and production; b) production and aquaculture (fig. 20).

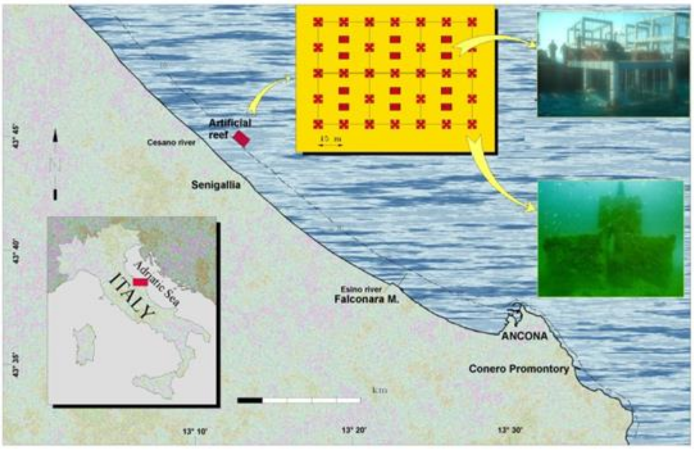

Fig. 20 – Italy: example of multipurpose artificial reef (protection, production and extensive aquaculture). A) production and extensive aquaculture cages; b) protection and production reef set (courtesy of CNR-ISMAR Ancona).

These artificial reefs were usually located close to the coast and at low depth (~ 10 m) to facilitate the mussel harvesting by professional scuba divers.

5.5.4.3 Protection, production artificial reefs and Marine Protected Areas

Artificial reefs can be also associated with Marine Protected Areas.

France – From 1983 to 2004 4,884 m^3 of production (2,684 m^3) and protection (2,200 m^3) artificial structures were deployed in the Côte Bleue Marine Park (fig. 21). Part of these man-made structures were placed within and around the 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 establishment of the Marine Protected Area and deployment of artificial reefs were used as complementary tools which contributed to preserve the traditional small-scale fisheries and the same number of fishermen (around 60) in the Côte Bleue territory. Oppositely, these fishing activities are decreasing in the nearby zones (Charbonnel and Bachet, 2011).

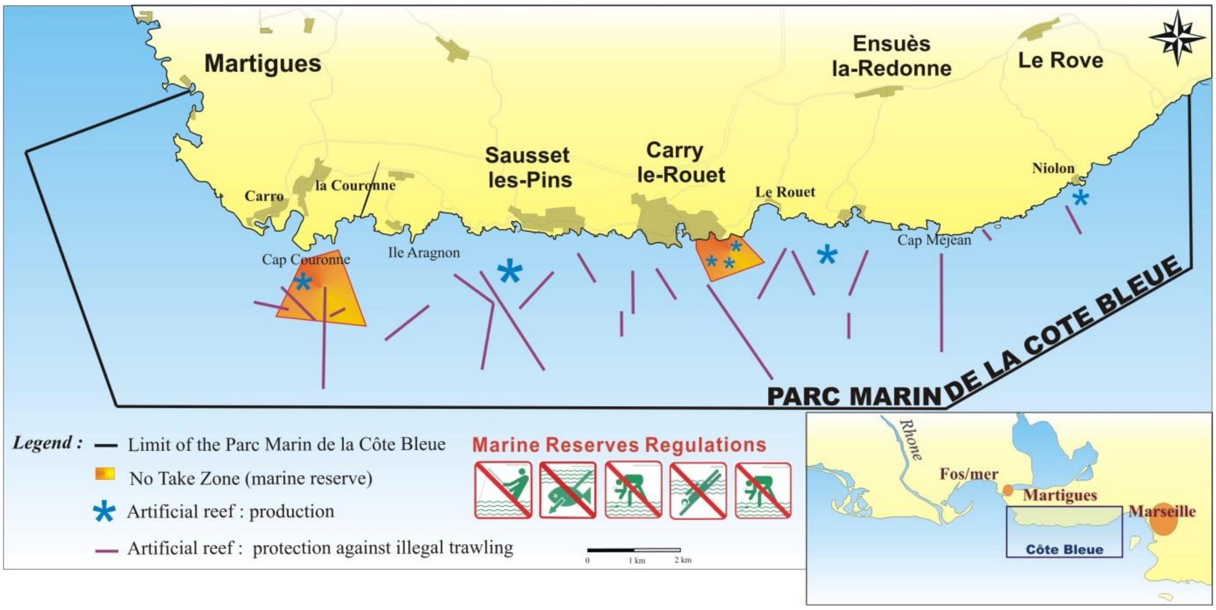

Figure 21 – France: multipurpose artificial reefs associated with Marine Protected Areas. Case of Côte Bleue Marine Park (from Charbonnel and Bachet, 2011).

6. POSSIBLE NEGATIVE IMPACTS

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

During artificial reef installation, the presence of work vessels and other mechanical equipment can result in the release of pollutants into the environment that might accumulate in the sediments. Moreover, the immersion of the artificial substrates may induce a short-term increase of turbidity due to sediment disturbance temporarily altering photosynthesis of algae, seagrasses and corals.

Sediments suspended during construction can also settle out the surrounding locations where they may smother existing communities. The extent of the problem will depend on the volume of sediment which is disturbed and by local currents.

Once an artificial reef has been deployed, there may be some long-term environmental changes. These can consist of the modification of bottom currents leading to subsequent variations in the grain-size distribution and eventual localised sediment scour close to reef modules (fig. 22). An additional effect might be the change of sediment organic content due to the metabolic activity of benthic and fish assemblages associated to the reef. These effects will likely modify the original soft bottom community inhabiting the surroundings. Such modifications can be positive or negative. For example, a production artificial reef deployed on a seabed habitat degraded by organic polluted sediments can induce the development of a new, more productive, biological community in respect to previous one. 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.

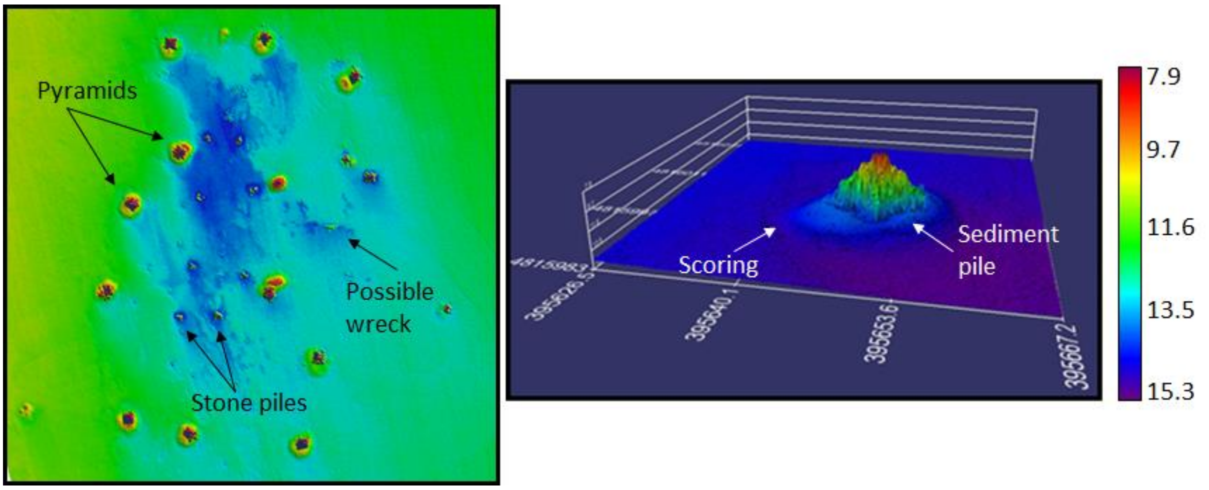

Fig. 22 – Adriatic Sea: acoustic images of an artificial reefs showing the modifications of sediment distribution induced by the artificial substrates. The strong current down scoring eroded the sea bottom at South of the reef sets raising each of them on a sediment pile (courtesy of CNR-ISMAR Ancona).

Artificial reefs may also cause negative impacts on the fish resources, especially in cases where the reefs change the spatial redistribution of exploitable biomass simply aggregating it without increasing the total stock. This is the case of Type C and Type D fish (see chapter 5.2.2). In the absence of adequate management measures, higher density at the reef increases their probability to be caught. The 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 to 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 degradation of the reef environment.

A further concern regards the potential contribution of artificial reefs to the introduction and expansion of non-indigenous species as the artificial reefs provide these invasives with suitable habitats that were previously absent. Analysis of risks should be performed prior the deployment an artificial reef to evaluate the vulnerability of the designed reef site towards invasive non-indigenous species.

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

Table 2 reports a list of the possible negative impacts generated by artificial reef deployment. For the most part, these impacts can be mitigated or avoided by careful planning and appropriate selection of sites, construction materials and design of reef units based both on 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	Shortening 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	Adopting 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	To forecast a buffer surrounding the reef; to place the reef far from sensitive habitats

Table 2 – Continue.

	Impact	Source	Effect	Duration of the effect	How to mitigate / avoid the impact
Environmental impacts	Increased predation on some fish species	Design of the reef units; Increased availability of preys	Increase of natural mortality	Medium-long	To 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 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; to forecast the presence of holes and refuges of different size in planning the reef units; to develop adequate plan 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	To avoid placement of units provided with iron/steel fishing devices inside the artificial reef when the reef is constructed for enhancing small-scale fisheries
Socio-economic impacts	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
	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

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 depends on 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 programs that will provide fisheries scientists and managers the information required to test objectives (Claudet and Pelletier, 2004). Artificial structures, particularly in the initial phase following deployment, demonstrate an ability to support greater fish abundance, diversity and biomass than similar naturally occurring habitats (Pickering and Whitmarsh, 1997; Wantiez and Thollot, 2000; Chou et al., 2002; Arena et al., 2007; Relini et al., 2007). Differences in the assemblage structure and recruitment patterns are further complicated by the relatively small size and isolated nature of many artificial reefs. Here, elements that help clarify a Mediterranean standardization of monitoring programs for the artificial reefs are provided.

7.1. CRITICAL ASPECTS IN THE MONITORING PLANS

Scientific research into 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 favourable to using artificial reefs as part of an alternative management strategy, but they would need of 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 include them into management plans, a more realistic approach would be to focus research on the gathering of data on specific areas of interest.
Therefore, a performance monitoring plan should be developed since 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, basing 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.

7.2. THE 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 chapter 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, 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 affect different types of artificial reefs and how the physical conditions of the reef influence the succession of reef communities over time. The monitoring should start just after the artificial reef deployment to verify the right position of the reef structures, and continue over all the life of the artificial reef.

Acoustic systems (single-beam echosounder, multibeam echosounder, and side scan sonar) are efficient tools capable of monitoring the environmental (physical and biological) evolution around artificial reefs (fig. 23), whereas visual dive and ROV inspections can be limited by water turbidity.

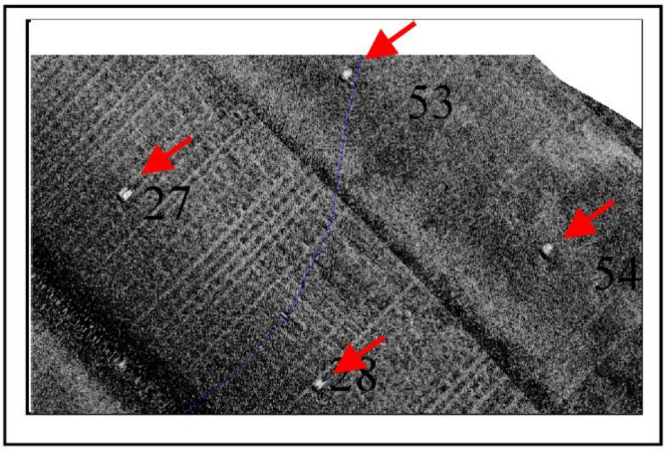

Fig. 23 – Spain: side scan sonar georeferenced image of units in the protection Santanyi artificial reef, Mallorca, Balearic Islands (courtesy of Balearic Islands Government).

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 multibeam echosounders 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 during a survey due to the very accurate navigation available from differential GPS or similar systems (fig. 24).

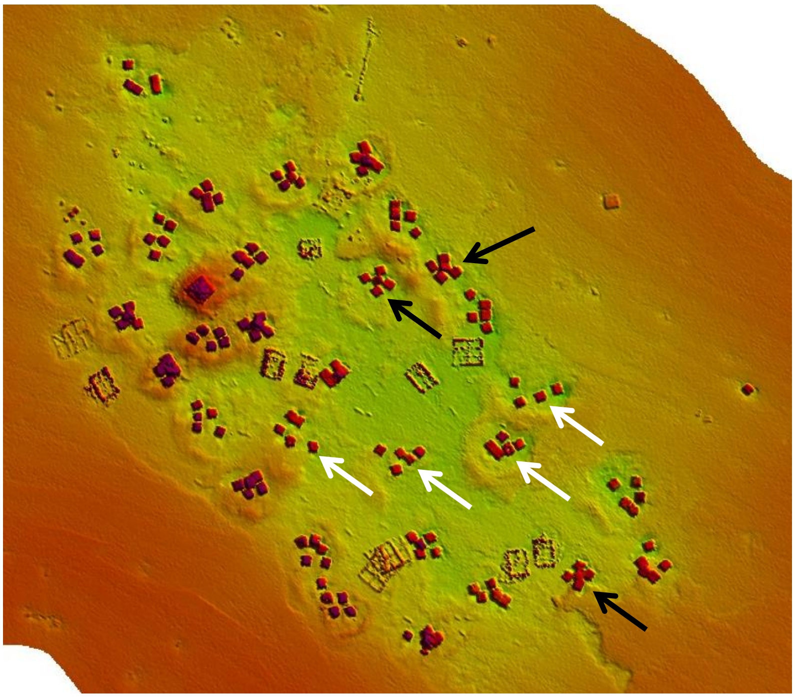

Fig. 24 – Italy: multibeam echosounder image of on artificial reef in the Adriatic Sea 21 years after deployment. Some reef sets have maintained their original structure (black arrows), while others have collapsed (white arrows) (courtesy of CNR-ISMAR Ancona).

These high-resolution systems are able to acquire 100% 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 used 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).

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.

7.2.2.1 Soft-benthic communities

Most of the researches on infauna surrounding artificial reefs dealt with the macrofauna group-size components, but meiofauna should be also 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. 25). 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.

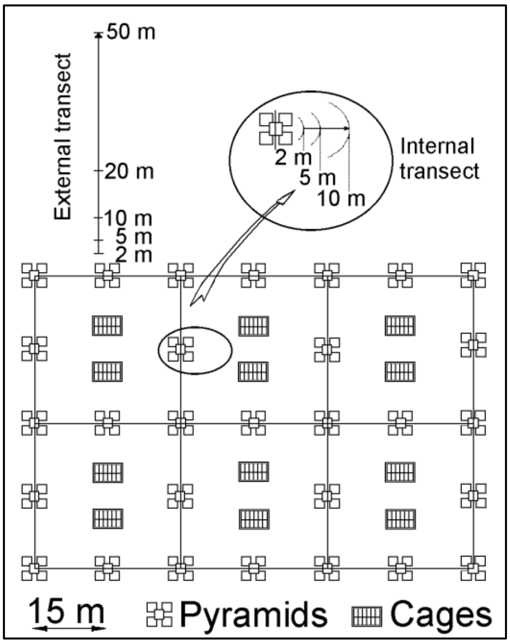

Fig. 25 – Example of sampling plan of the soft-bottom benthic communities at an artificial reef (from Fabi et al., 2002).

7.2.2.2 Epibenthic and algal communities

The technical features of the artificial reef, such as material, 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 on nurseries and food sources for herbivorous fishes (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 enough replicates in space and time. The number and size of samples depend on the spatial variability: the most variability requires more and larger samples (Moreno, 1996). Sampling must be simple and fast, because they must be carried out by SCUBA divers. For this reason, it is important that the protocol is standardised and well defined.

7.2.2.3 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. Photography may be used to estimate fauna and flora species composition, number of organisms, percent cover and relative density of the sessile community. It also allows 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, but 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 for 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 the communities inhabiting the soft bottoms outside an artificial reef and between the structures constituting the reef. Grab samplers 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 but, at the same time, 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 it is usually required 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 but not inside because of the presence of the reef structures. Dredges are not able to adequately sample pre-defined quantities of sediment, hence they are unable in the case of quantitative studies (Castelli et al., 2003).
Suction samplers: these samplers are used to investigate soft-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). They allow sampling the exact sampling point because these instruments are directly operated by scuba divers, but may require for 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 may require for a great effort by divers. In addition, it may be possible to loose part of the sample, especially small-sized organisms, due to underwater currents.

7.2.3. FISH ASSEMBLAGE

7.2.3.1 Sampling methods

Non-destructive methods
Visual census (UVC): Visual census 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 and the species encountered.

- *Point count*: the diver stand 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 fishes accurately and record their presence under variable conditions (Sale, 1997). Moreover, the different fish species react in different way to the presence of the diver, some escaping and others coming closer, so making difficult to census them with a same level of accuracy.

<u>Baited remote underwater video (BRUV)</u>: recent innovations in the development of video technology have resulted in the widespread use of baited remote underwater video as a means of monitoring 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).

<u>Hydroacoustic tecniques</u>: the most recent advancement in artificial reef research involves using stationary or mobile hydroacoustic technology (e.g., echosounders for fish, multibeam echosounder) 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, around oil and gas platforms (Thorne et al., 1990; Thorne, 1994; Stanley et al., 1994; Stanley and Wilson, 1998; Soldal et al., 2002); however, thus far applying this technique to artificial reefs has been very limited (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 computerised 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 multibeam echosounder (MBES) is able to detect at the same time the seafloor and the water column. 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 arrangement, distance, shape and dimensions of 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 base maps for seafloor investigation and interpretation (Todd et al., 1999; Mosher and Thomson, 2002) helping to better understand the evolution of the fish assemblage associate to an artificial reef in respect to 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. 26).

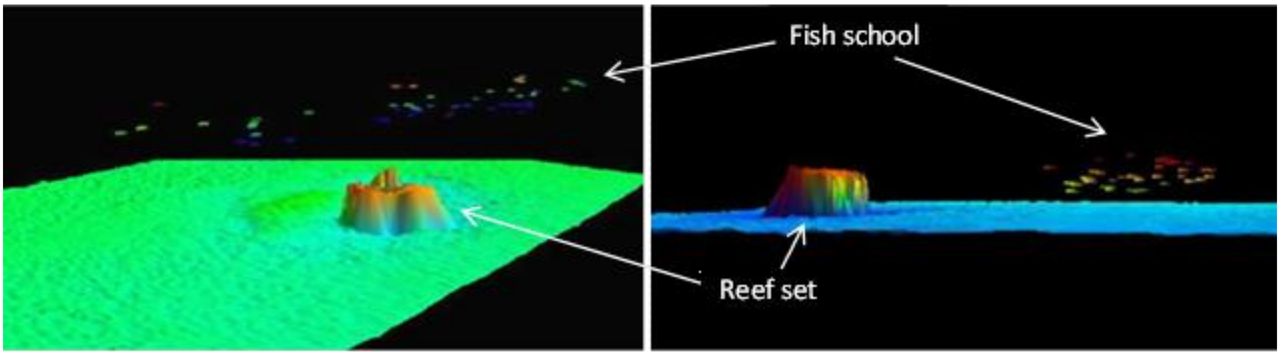

Fig. 26 – Italy: Mmltibeam echosounder images of fish schools around artificial reef structures in the Adriatic Sea (courtesy of CNR-ISMAR Ancona).

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

Destructive methods

These methods include adaptations of commercial fishing techniques such as traps, long-lining and set netting (Gannon et al., 1985; Kelch et al., 1999) as well as trawling.

Trawling is the less suitable technique because, due 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 at the reef. Nevertheless, protection artificial reefs aimed 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 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. The artificial reefs consist of groups of concrete blocks with a separation of 130 m between blocks and 2 km between groups of blocks. The surface area occupied by the blocks was less than 2% of the whole area (fig. 27; Serrano et al., 2011).

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

Oppositely, the potential habitat degradation due to the use of fishing gears, the unfeasibility 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).

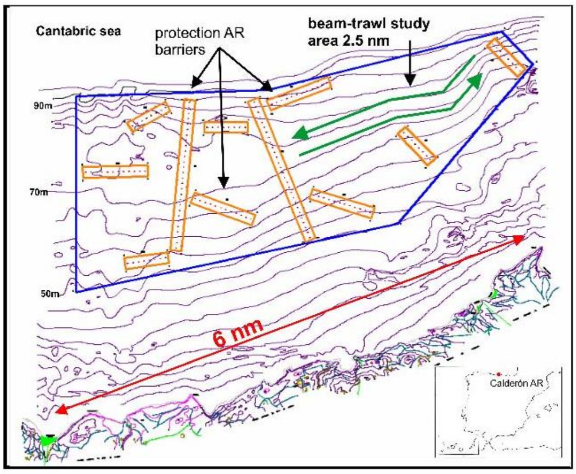

Fig. 27 – Spain: protection artificial reef of Calderón, Cantabria coast, deployed in an area subjected to scientific trawl surveys (courtesy of J.J. Goutayer Garcia).

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

The new perspectives monitoring 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. THE STATISTICAL FRAMEWORK

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

The statistical framework that has to be developed to better evaluate the biomass associated with artificial reefs, thus determining the effectiveness of artificial reefs for the development of benthic communities, stock enhancement and fishery management, needs to be related to the following new and comprehensive statistical methods:

- BACI/ACI and Beyond BACI designs;
- ANOVA, MANOVA (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 analyses.

7.3.1 STATISTICAL METHODOLOGIES

7.3.1.1 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 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, 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) discussed 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' (After-Control/Impact) 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 on-going, 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).

7.3.1.2 ANOVA and MANOVA (PERMANOVA)

The analyses of variance has been utilized since the beginning of the development of the studies about artificial reefs (Fabi and Fiorentini, 1994). In the case the replication is appropriately designed and the assumptions are fully met, the method provides a robust statistical framework to evaluate the changes in both fish and benthic communities. The main issue is that, especially in the multivariate analyses (MANOVA), it is quite unrealistic that data are normal 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).

7.3.1.3 Non parametric methods

Non parametric tests are numerous with different purpose; in the following paragraph short descriptions of the most utilized tests is provided. The Kolmogorov-Smirnov test assesses the hypothesis that two samples were drawn from different populations and is usually employed to compare frequency distributions. Unlike the Mann-Whitney U test, which test 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).

7.3.1.4 Time-series analyses

Time-series analyses are used when observations on artificial reefs are made repeatedly over long time periods (more than 20-25 years). One goal of the 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 enlargement of an artificial reef or open the reef to fishermen). 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.

7.3.2. 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 development of prey resources for resident species, few have explicitly attempted to isolate reef effects. 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 the 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. It is quite challenging to indicate the correct number of reference sites, 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 3 to provide enough data to accomplish one of the statistical methods listed before.

Whatever the typology of the study and 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 in doubt about the relevant spatial scale, it is suggested to use a design that can detect changes or differences at one or more of several of the possible scales.

In studies with frequent sampling, high variability in abundances of individual species is 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 between attraction and production. Artificial reefs and reference sites should be visited at intervals relevant to life history events, e.g. every 1–2 months to permit comparisons between and within seasons and detect abundance changes related to recruitment and mortality.

To test for seasonal or other a priori selected scales of temporal variation, temporal variation among the factors of interest must 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 fishes through the water column.

Different scales of temporal sampling are extremely important for identifying 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 drops 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 to 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 1980s (Bohnsack and Sutherland, 1985) there is still a general lack of studies dealing on this issue and most of them focus on areas with the greatest concentration of artificial reefs such as Japan and USA (Milon, 1988; Rhodes et al., 1994; Ditton et al., 1995; Simard, 1997; Bell et al., 1998; Milon et al., 2000). Independently from the purpose of an artificial reef, usually its performance and efficacy is judged on the basis of the public satisfaction. Collection and evaluation of socio-economic data is useful to quantify the usage and public benefits of an artificial reef helping to justify costs for the construction, maintenance and providing information for a 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 prior the artificial reef construction or on already existing artificial reefs. It 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 the ecological and the environmental issues.

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

1. *monitoring of utilization patterns*: it serves to evaluate 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, replace or restore damaged natural habitats. The techniques for data collection and evaluation to be used in this step are: i) direct observation of activities in the area; ii) on-site interviews; iii) mail or phone surveys. These techniques can be applied individually or in combination. Data collection should not be conducted on a one-time basis or in short time period as the perception of stakeholders may be easily influenced by events and change in a few days.
2. *Impact assessment*: it includes social assessment and economic assessment and is aimed to understand the social and economic importance of an artificial reef for the local communities assessing the changes induced by the project and evaluating whether these changes fit with the specific objectives. For example, if a goal of an artificial reef project was to increase the local economy by XX% improving recreational fishing and attracting non-resident fishermen, 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*: it is aimed to evaluate the economic performance or net benefits of the artificial reef. Efficiency analysis can be classified as either cost-effectiveness or cost-

benefit evaluations. The former is aimed to 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 analysis provide information on whether the reef project is economically sustainable. They can be also used to compare the efficiency of different artificial reef projects or to compare the economic performance of the reef project with 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 use occur?
- Where does use occur?
- Why does 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 development and usage?
- 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 project benefits exceed the project 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 fishermen, recreational divers, professional fishermen, 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 groups the can get benefits from the artificial reef deployment but also to those which oppose 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 usage of the artificial reef 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 and to understand their position towards the reef project. It also helps to 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 the artificial reef project and, once the reef has been constructed, to plan adequate management measures to avoid or reduce conflicts.

9. ARTIFICIAL REEF MANAGEMENT: CONTROL, SURVEILLANCE AND MANTAINANCE

Similar to other types of aquatic environments, artificial reefs may require some degree of management either to assure that they provide the desired outcomes for both the biological resources and users. Additionally, effective management can help reduce potential risks such as damage to fishing gears, 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 after the deployment of an artificial reef. This plan should include simple actions, such as to indicate the reef location on nautical charts to avoid damages to fishing gears and to provide diver safety guidelines to prevent injuries to people diving at the artificial reef, as well 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 to assess the structural performance of the artificial reef on time, to assess whether the artificial reef provides the expected benefits from the ecological and environmental point of view and to evaluate the efficiency of the applied control measures.

The involvement of stakeholders in the artificial reef management is crucial. Professional and recreational fishermen and divers can provide support in reef monitoring and evaluation. Applied research is another key element in artificial reef management programs providing assistance in monitoring the activities carried out at the reef, evaluating the efficacy of the adopted management measures and, where necessary, identifying actions to be undertaken and 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 as they act by themselves as a management tool to impede illegal trawling/dredging in sensitive habitats. Nevertheless, they would need of 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, access to them should be totally forbidden to any kind of activity except for research, which should also monitor the physical condition 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). The open-access may lead to overexploitation and rapid depletion of the reef resources and conflicts within and between user groups. This usually happens where the artificial reefs are created by public agencies in public waters without effective restrictions on access by the 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 each other and may result from either incompatible uses (e.g., recreational and commercial fishing), incompatible fishing gears or too many users in a limited site. Stock and congestion effects are not mutually exclusive (Samples, 1989).

Some basic options for artificial reef management can be identified (fig. 28):

1) selective access control: it may consists in the establishment of property or user rights in which local fishermen 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 constrains which explicitly forbid to discriminate between different groups of users (Whitmarsh et al., 2008). This measure is efficiently applied in Japan, where fishermen cooperatives are granted exclusive commercial rights to regions of coast line, thus prohibiting other user groups from harvesting from artificial reefs (Polovina and Sakai, 1989; Simard, 1997).

2) Gear and catch restrictions: this measure is aimed to orient harvesting strategies at the artificial reef through the use of selective fishing gears to allow optimal fishing yields and avoid the disruption of the natural succession of the artificial reefs and associated assemblages; the exploitation strategies should include different fishing gears to diversify the catches and exploit all the reef resources to avoid alterations in the equilibrium among the functional groups of fish and macroinvertebrates inhabiting the reef. Gear restriction has been successfully adopted to manage artificial reefs in USA (Mcgurrin, 1989; National Marine Fisheries Service, 1990).

3) Temporal closure: it can be adopted to avoid exploitation of the 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 aimed to separate 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 fishermen) are easily distinguishable. 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 of creating separate artificial reef sites for each user group. Nevertheless, creating and maintaining multiple artificial reefs are much more expensive than the other control options.

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 selective access control, setting catch limits (size and number), by limiting fishing gears and selectivity, and by setting temporal catch limits (temporal closure for fishing).

Congestion effects can be reduced by selective access controls, by gear restrictions, and by 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 fishermen (small-scale or recreational fishermen) and/or recreational divers, as well as research in the artificial reef management is fundamental.
Basing on the results of biological monitoring and feed-back from the socio-economic data collection, it will be possible to evaluate at regular time intervals the level of efficacy and of approval of the management measures in place and to reformulate them, if necessary, following a flexible, adaptive approach.

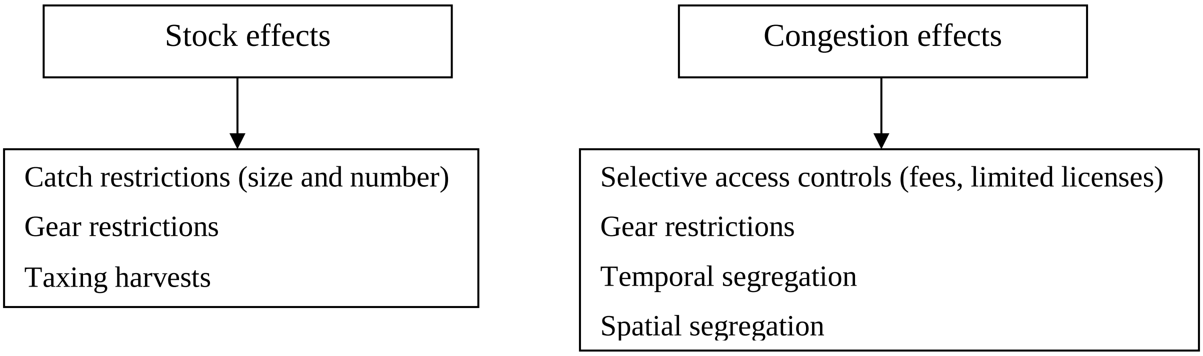

Fig. 28. Habitat management controls to reduce users conflicts (modified from Samples, 1989).

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