# OVERVIEW ON ARTIFICIAL REEFS IN EUROPE*

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## ABSTRACT

Artificial reefs in Europe have been developed over the last 40 yrs. Most of these reefs have been placed in the Mediterranean Sea, but there is an increasing interest on the part of northern European countries. Fish stock enhancement and fishery management are the main purposes of reef construction in the Mediterranean Sea and on the Atlantic coast of the Iberian Peninsula, while nature conservation/restoration, research, and recreation have been the main purposes served in the other European regions to date. Artificial reef deployment falls under some general regulations concerning the protection of the sea against pollution due to the dumping of unsuitable materials. Specific Regional Plans relating to the use of artificial reefs in the marine environment and Guidelines for reef construction have been derived from these general regulations. In spite of recent developments, national and/or regional programs for the deployment of artificial reefs and/or their inclusion in overall management plans for integrated management of coastal zones are in force only in the majority of Mediterranean countries, while only a few projects have, to date, been undertaken in the other European Regions. Moreover, there is a noteworthy lack of plans, in many countries, for the management of the reefs after their deployment.

## RESUMO

Os recifes artificiais, na Europa, foram desenvolvidos nos últimos 40 anos. A maioria desses recifes foram instalados no Mar Mediterrâneo, mas despertam um interesse crescente por parte dos paises do norte europeu. O incentivo aos estoques pesqueiros e o manejo da pesca são os principais objetivos da construção de recifes no Mar Mediterrâneo e na costa Atlântica da Península Ibérica, enquanto a preservação / recuperação da natureza, a pesquisa e a recreação tem sido os principais objetivos das demais regiões européias até hoje. A implantação de recifes artificiais está submetida a algumas regulamentações básicas quanto à proteção dos oceanos com relação à poluição devido ao despejo de materiais. Projetos Regionais específicos relativos ao uso de recifes artificiais no ambiente marinho e Instruções para a construção de recifes são decorrentes dessa Regulamentação Geral. Apesar de avanços recentes, programas regionais e/ou nacionais sobre a instalação de recifes artificiais e/ou a sua inclusão nos planos gerais de planejamento para a gestão integral das zonas costeiras tem mais destaque somente em grande parte dos paises do Mediterrâneo, enquanto que, poucos projetos até hoje tem sido realizados nas outras Regiões Européias. Além disso, em muitos países, há uma notável falta de projetos para o manejo dos recifes, depois de instalados.

Descriptors: Artificial reefs, Management, Baltic, Mediterranean, NW Atlantic, Black Sea.
Descritores: Recifes artificiais, Manejo, Mar Báltico, Mar Mediterrâneo, Atlântico Noroeste, Mar Negro.

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## INTRODUCTION

The use of artificial structures to attract fish goes back to around 3,000 years ago. At that time the rocks utilised as anchors for the tuna fishery nets in the Mediterranean Sea were left on the seabed at the end of each fishing season, accumulated over time and made new rocky habitats inhabited by fish which were exploited by local fishermen in the periods between the tuna fishing seasons (RIGGIO et al., 2000). It is likely that artisanal fishermen used similar practices world-wide at the same time (SIMARD, 1995).

In the middle of the 17th century artificial reefs, of various shapes, were set up in Japan to attract fish. The modern concept of "artificial reef" was born in that country in the following century and spread to the USA at the beginning of the 1800s. In Europe, this concept was adopted in the second half of the 1900s and artificial reefs have been deployed in many countries since then.

This paper seeks to provide a general picture of the artificial reef programs which have been carried out or are currently under consideration in the various European countries. Information has either been extracted from official literature and/or has been provided by researchers involved in artificial reef research.

In general, four distinct areas may be identified in Europe: the Baltic Sea, the OSPAR Maritime Area including five Regions (the Arctic Waters, the Greater North Sea, the Celtic Seas, the Bay of Biscay and the Iberian Coast, and the Wider Atlantic), the Mediterranean Sea, and the Black Sea.

Most artificial reefs are located in the Mediterranean Sea (Fig. 1) where they are mainly used for fisheries management, that is, the protection of coastal areas or other sensitive habitats against illegal trawling, the enhancement of small-scale fisheries and the reduction of conflicts among different fishing activities.

Some 56 artificial reefs have been constructed or are being planned in the different regions of the OSPAR Maritime Area, except for the Wider Atlantic (Fig. 1). The largest concentration of reefs is in Region IV - the Bay of Biscay and the Iberian Coast. The driving motives for artificial reef construction in the OSPAR Maritime Area are fisheries protection and production, habitat protection and enhancement, research and recreation (OSPAR COMMISSION, 2009).

Very few artificial reefs have been deployed in the Baltic and Black Seas (Fig. 1). In these areas the main goals are habitat restoration and conservation as well as a reduction of the eutrophication and pollution level (self-purification processes) due to fish farming, the discharge of contaminants from industry, and other human activities.

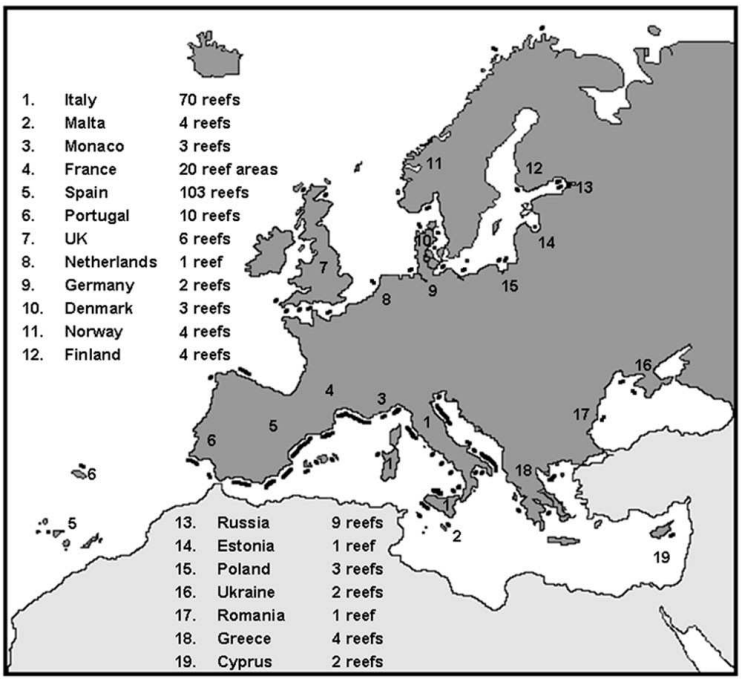


Fig. 1. Locations of artificial reefs in Europe.

## INTERNATIONAL REGULATIONS

Despite the potential benefits derived from the deployment of artificial reefs, their increasing use in European coastal areas has given rise to some concerns regarding the possible negative impacts especially due to the use of unsuitable materials and the dumping of waste. Therefore, while there are currently no binding regulations on the placement of artificial reefs, some guidelines and protocols have been drawn up in the different European regions.

Artificial reef deployment falls under some general regulations, set out below, concerning the protection of the sea against pollution due to the dumping of unsuitable materials:

- London Convention - Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972; replaced by the Protocol in 1996)
- OSPAR Convention - Convention for the Protection of the Marine Environment of the North East Atlantic (adopted in 1992 and in force since March 1998); this replaced the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircrafts (Oslo Convention).
- Barcelona Convention - Convention for the Protection of the Mediterranean Sea against Pollution (1977).
- Helsinki Convention - Convention on the Protection of the Marine Environment of the Baltic Sea Area (1992; in force since 2000) signed by all the States bordering on the Baltic Sea and by the EC.
- Bucharest Convention - Convention on the Protection of the Black Sea against Pollution (1992; in force since 1994).

More specific Regional Plans which refer to the use of artificial reefs in the marine environment and/or Guidelines for the construction of artificial reefs have been derived from the above general Conventions. Examples are represented by the "Guidelines for the placement at sea of matter for purpose other than mere disposal (construction of artificial reefs)" (UNEP MAP, 2005) and the "OSPAR Guidelines on artificial reefs in relation to living marine resources (OSPAR COMMISION, 1999).

These guidelines state that an artificial reef is "a submerged structure deliberately placed on the seabed to mimic some functions of a natural reef such as protecting, regenerating, concentrating and/or enhancing population of living marine resources". The objectives of an artificial reef may also include fisheries protection and production, habitat protection and restoration, research and recreation. The term does not include submerged structures such as artificial islands, cables, pipelines, platforms, moorings, and structures established for the defence of the coastline (e.g. breakwaters).

Materials, design, placement, administrative actions, monitoring, scientific experiments, management and liabilities are also addressed. The purpose is to assist Contracting Parties in:

- assessing proposals for the placement of artificial reefs on the basis of scientifically sound criteria and development of an appropriate regulatory framework;
- implementing regulations on the artificial reefs´ construction;
- preventing pollution or degradation of the marine environment as a consequence of waste discharge.

Although the guidelines are not legally binding, the result is that most of the reefs deployed over the last two decades have been accurately planned, subjected to environmental impact assessment and carefully monitored to evaluate their effects.

## MEDITERRANEAN SEA

**Cyprus -** The construction of artificial reefs represents a recent technology in Cyprus. The UNEP-MAP program "Integrated Coastal Area Management in Cyprus: Biodiversity Concerns" developed in 2007 indicates the artificial reefs as one of the most effective actions to stop illegal trawling. Consequently, a specific Strategy for Artificial Reef Deployment has been recently formulated by an *ad doc* Committee under the coordination of the Department of Fisheries and Marine Research of the Ministry of Agriculture, Natural Resources and the Environment of Cyprus (DFMR), with the participation of the Cyprus Tourism Organization and the Cyprus Diver Center Associations.

Artificial reefs are considered a tool for increasing marine biodiversity, impeding illegal trawling, enhancing fish stocks, increasing marine productivity, improving small-scale coastal fisheries, and developing recreational diving.

The first pilot artificial reef was deployed in the Amanthus area (southern Cyprus; Fig. 1), and three others have been planned for the next future. Another reef has been planned off İskele (northern Cyprus), promoted by the İskele Fishermen Solidarity Association for Development and İskele Municipality. All reefs will be co-financed by the European Community.

Specific studies regarding the ecological features of the area, substrate stability, biocoenosis, occurrence of sensitive habitats, and biodiversity level are required for the selection of reef sites. These studies have to be associated with an assessment of the possible impact on the marine environment of the materials used and the presence of the artificial reef

and a monitoring program including ecological, socio-economic, and fishery aspects is required after the deployment to evaluate the reef's effects.

Concrete modules provided with holes, randomly or geometrically assembled, are employed for reef construction (Fig. 2).

A Ministerial Order regarding the management of the existing artificial reef off Amanthus is to be published. Under the provision of this Order any fishing activity, vessel transit, and anchorage will be prohibited, except at two mooring sites.

**France** - France was the first European country to carry out experiments on artificial reefs, starting earlier in 1968 with some pilot reefs made of waste materials (car bodies). In spite of this, a concerted program was developed only in the mid-1980s, with the immersion of 30,000 $m^3$ of specially designed concrete modules to be assembled in situ (RELINI et al., 2008). Around 90,000 $m^3$ of reefs have been deployed to date at 20 sites along the French Mediterranean coast (Fig. 1).

Most artificial reefs are made of specially designed concrete units (Figs 2 and 3). Several kinds of production and protection modules have been tested. The production reefs are usually composed of small cubic modules of 1-2 $m^3$ volume, usually gathered into chaotic piles of 50-150 $m^3$, and bigger modules (158 $m^3$) derived from Japanese technology. Several kinds of structure have been used for anti-trawling reefs. It has been estimated that, to be efficient, the protection units should have a minimum weight of 8 t. They are separately deployed, spaced 50-100 m from each other, and can be either regularly placed over the whole area, or deployed in lines perpendicular to the coast.

Several actors having diverse interests - administrators, professional fishermen, scientists, and environmental associations - are commonly involved in artificial reef placement and are required to discuss and validate the project from the scientific, technical and administrative points of view. The license to occupy the seabed is issued by the Regional Prefectures.

Reef construction is usually associated with multi-year monitoring surveys for the purpose of evaluating the reefs´ effects on the marine environment and the living resources.

Reef management varies in the different areas: in Languedoc all reefs are open to fishermen, while in Provence-Alpes-Côte dAzur most of the reefs are located in protected areas where fishing is prohibited. An intermediate situation occurs in the Côte Bleue Marine Park where some reefs are open to professional and recreational fisheries and others are subject to protective management. However, in the case of open access to the reefs, there is a general need of a management regulation either from fishermen, financiers or contractors.

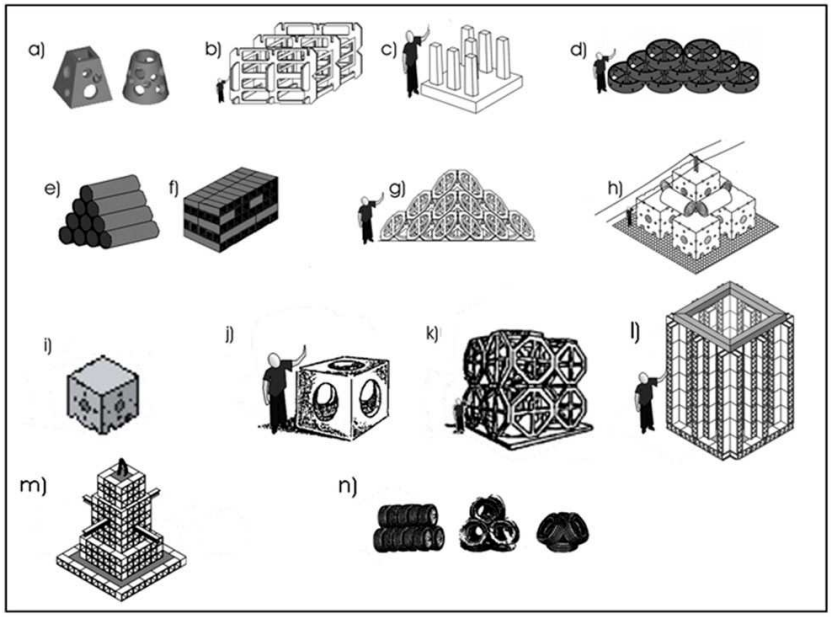


Fig. 2. Examples of modules employed for artificial reef construction in Europe. a) Cyprus; b), c) France; d) Germany; e), f) Greece; g), h) Italy; i) Poland; j), k) Portugal; l), m) Spain; n) United Kingdom.

Fig. 3. Pictures of some artificial structures deployed in the European Seas. a) Languedoc-Roussillon, France; b), c) Nienhagen, Germany (manhole rings, from NICKELS et al., 2006); d), e) Greece; f) Sicily, Italy; g) Larvotto Reserve, Monaco (www.gouv.mc); h) Nordfjorden, Norway (from HARTVIG, 2007); i), j) Algarve, Portugal; k) Odessa, Ukraine (from COLLINS, *www.soes.soton.ac.uk* ); l) Pool Bay, United Kingdom (from COLLINS, *www.soes.soton.ac.uk*).

**Greece** - The construction of artificial reefs in Greece started in 2000, within the framework of the Multiannual Programme for Fishery Development which includes specific action regarding the placement of artificial reefs as tools for the protection and management of fishery resources. Reef construction and monitoring falls under the responsibility of the Ministry of Agriculture, which also provides for the necessary funds. The Ministry of Agriculture has also identified the new reef sites up to 2004. Since then local fishermen's associations, through the local Prefectures, have taken the initiative of promoting new reef locations.

The legal procedure for artificial reef deployment requires a feasibility study which establishes the new reef site on the basis of: a) the environmental features of the area and the suitability of the substratum; b) the local fish assemblage; c) the existence of sensitive ecosystems important for exploitable species or areas under specific regimes (i.e. Natura 2000, marine reserves, etc); d) the economic dependence of the area on fisheries; and e) socio-economic aspects of the local fisheries.

The second step is to obtain permission from all the Authorities whose competence relates to the management of the sea, such as the Archaeological Authority, whose opinion is crucial in Greece, the Ministry of Maritime Affairs, the Ministry of the Environment and the Hydrographic National Authority.

Once the above authorizations have been obtained, four additional studies are required before the deployment of the artificial reef is permitted: a) an ichthyologic and oceanographic study of the area; b) a construction study; and c) an environmental impact study.

A 5-yr monitoring survey has to be carried out after the reef´s deployment. It includes oceanographic investigations, investigations of the fish assemblage both inside the reef and in the surrounding

areas, studies on the colonization of the structures by benthic organisms, and monitoring of the catches at the nearest fishing ports.

Four artificial reefs made of different concrete modules, each with a surface area of 8-10 $km^2$, were constructed in the period 2000-2006. Mixed modules, consisting of concrete cubic blocks provided with holes and deployed one by one on the seabed or assembled in pyramids were the commonest units. Production modules, such as bulky cement-bricks on a concrete base, and concrete pipes assembled in pyramids were also employed (Figs. 2 and 3).

Six new sites have been proposed and it is likely that new locations will be added in the next few years. It has been established that 10 $km^2$ shall be the minimum surface area of the new reefs.

All the artificial reefs deployed in the past have been completely financed by the Ministry of Agriculture, while the feasibility studies to identify the new locations were funded by the local Prefectures.

**Italy** - The first artificial reef was deployed in 1970 (RELINI, 2000), and more than 70 reefs have so far been constructed along the Italian coasts (Fig. 1). Most of them are medium- or large-scale reefs, while only a few are small-scale experimental reefs used for research.

Fisheries management is the main purpose for artificial reef construction which is regarded as a means for protecting the coastal nursery areas or other sensitive habitats (e.g. coralligenous, seagrass beds, submerged caves) from illegal trawling, reducing conflicts between different fishermen categories (e.g. small-scale fishers and trawlers), and enhancing small-scale fisheries by increasing local finfish populations and, in eutrophic waters, by developing new populations of edible bivalves (i.e. mussels).

No national artificial reef program exists. A few years ago the construction of artificial reefs was devolved to the Regional Authorities and may be included in the annual or multi-year Regional Plans for Fisheries and Aquaculture. Bureaucratic procedures and regulations can vary from one region to another, but common restrictions exist regarding the materials which may be used in order to prevent the dumping of waste materials and the release of contaminating substances. No specific management plans are usually applied after reef deployment in the case of reefs constructed with public funds.

Most artificial reefs have been constructed with the financial help of the EC. However, projects may also be proposed and realised by local authorities and/or private associations (diving clubs, recreational fishing clubs, professional fishermen, etc.) which support the projects with their own funds. When the reef is constructed by private associations they have to submit the project to the Regional Authority for permission and have to lease an area of the seabed for the purpose.

Specific anti-trawling, production and/or mixed concrete modules are usually employed (Figs. 2 and 3; BOMBACE et al., 2000; FABI, 2006).

Multi-year monitoring programmes are usually carried out before and after the reef deployment to assess the effects of the structures on the environment and fishery resources. The investigations conducted after the placement of the reef study the stability of the structures, the natural soft-bottom benthic communities inside and outside the reef, the benthic community settled on the hard substrates, the finfish assemblage inside and outside the reef, and the fishing yields.

**Malta** - Malta has occasionally, since the late 1980s, deployed ships for recreational diving and tourism. The possible construction of an inert-waste reef was studied in 2002 and the Malta Environment and Planning Authority (MEPA) undertook a pilot project in 2004. It consisted of the placement of four artificial reefs off Balluta Bay (Fig. 1), two of which were constructed with globigerina limestone and two with concrete blocks arranged in pyramids. The reef construction and associated scientific investigations were funded by MEPA, through the Environment Initiative Partnership Programme (EIPP) that was begun in November 2001. The aim was to assess the environmental impacts, to compare suitability and time of colonization of different substrates by marine flora and fauna, and to evaluate the stability of the reef over time (BORG et al., 2005).

Artificial reef deployment in Malta is regulated by the Environmental Impact Assessment Regulations published in 2007 by the Minister for Rural Affairs and the Environment. These Regulations describe the overall bureaucratic procedures and environmental studies required for the installation of any man-made structure on land or at sea within the coastal zone, artificial reefs included. Depending on the artificial reefs´ dimensions, the projects have to be submitted either to a full environmental impact assessment (Environmental Impact Statement) in the case of installations occupying an area of 1 ha or more, or to a limited environmental impact assessment (Environmental Planning Statement) for areas ranging from 1,000 $m^2$ to 10,000 $m^2$.

MEPA is the competent Authority responsible for performing the duties set out in these Regulations. A number of procedures have to be followed in the preparation of the full environmental impact assessment, such as: a) description of the project; b) description of the extent of the existing environment likely to be affected by the project, and c) identification and assessment of the effects of the project on the existing environment. A series of other steps (e.g. consultation stage, review of the draft

environmental impact statement, certification of the Environmental Impact Assessment, public hearing, submission of the final environmental impact statement to the Authority, etc.) have to be taken before the reef´s construction.

A limited environmental impact assessment is quite similar but more limited and aims at appropriately identifying, describing and assessing, in the light of each individual proposal, the direct and indirect effects produced on the living and non-living components of the environment.

**Monaco** - Since 1976 a cooperative program involving governmental and civic interests has considered artificial reefs as a tool for the management of coastal resources. The programme was organized and managed by the Monegasque Association for the Protection of Nature (AMPN). All artificial reefs have been deployed in marine protected areas established along the Monaco shoreline (Fig. 1; ALLEMAND et al., 2000).

The first artificial reef deployment dates back to 1977 when 300 t of rocks were immersed at 28-30 m depth, but this project was unsuccessful as depth and arrangement of materials proved to be unsuitable to attract fish. Afterwards, stable habitats were employed.

Artificial reefs consisting of different types of modules, such as alveolar modules, alveolar caissons assembled in pyramids, and "Thalame" units having the shape of a turtle´s carapace were deployed in the Undersea Reserve of Monaco from 1979 to 1992 for the restoration and protection of *Posidonia* meadows and marine fauna. Funding was assured by AMPN with the technical support of the Government of the Principality.

Another artificial reef was deployed in 1988 inside the Coral Reserve and was established to protect the coral slope (*Corallium rubrum*). The goal of the reef, made of artificial caves each with a weight of 4 t. was the experimental cultivation of red coral. In this case, The Enterprise des Grands Travaux Monégasque planned the modules and financed most of the construction costs.

Recently (2007) an artificial reef was submerged in the Larvotto Underwater Reserve by AMPN in cooperation with the François d'Assise-Nicolas Barré School and the Ecole Bleue. A pyramid weighing 1.2 t made of breeze-blocks and concrete slabs was deployed for research and teaching purposes (Fig. 3).

**Spain** - Artificial reef deployment in Spain started in 1892, when the first legal and policy regulation on this issue was elaborated, even though no public funding was allocated for reef construction (REVENGA et al., 2000).

When Spain entered the European Community (1986), public interest in artificial reefs increased. As from the end of the 1980s the Spanish Government has promoted a policy of using artificial reefs as tools for fishery management and their deployment has been financed by public funds from the EC and from national and regional Spanish budgets.

A National Program and some Regional Programs are currently active in Andalusia, the Valencia Region, Catalonia, and the Balearic Islands. Further, artificial reefs are commonly mentioned in Spanish fishery laws.

The Royal Decree 798/1995 and the "Methodological Guidelines for Artificial Reef Placement", produced by the Spanish Ministry of the Environment and Rural and Maritime Affairs in 2008, regulate artificial reef construction. Besides analysing the different categories of artificial reefs employed in Spain and their environmental effects, these documents establish the methodology for the installation of the reefs and the administrative procedure required for obtaining the authorization for their placement at sea. Moreover, they give advice on the post-placement monitoring programs to be adopted.

Projects are promoted by Public Administrations together with fishermen´s associations. Being constructed with public funds, artificial reefs are part of the public domain and, hence, are not subject to exclusive exploitation rights and no rules are usually applied for their management, although regulations regarding special uses can be established in some areas. Only one private project for recreational purposes, consisting of the sunken ship "Boreas", exists in Catalonia (NE Spain).

As artificial reefs are a tool of the Spanish fisheries´ policy, the sites for their placement are selected basing on fisheries´ management purposes.

The legal procedures require an overall study on the environmental features of the site, habitats, resources and their use, existing infrastructures, and socio-economic aspects. This study has to be associated with a technical project and both of them have to be approved by the respective governmental departments and public opinion. A 5-yr monitoring program has to be undertaken after the deployment of the reef. Investigations include: a) side scan sonar surveys for monitoring the structural quality of the reef and the *Posidonia* meadows; b) biological studies of the fish and benthic communities; c) fisheries control studies, and d) surveys among fishermen and other users.

More than 103 artificial reefs have, to date, been deployed along the Spanish coasts. Most of them are located in the Mediterranean (Fig. 1).

The main goals of their deployment are: a) protecting and enhancing fish stocks; b) impeding illegal trawling; c) protecting sensitive ecosystems

(e.g., *Posidonia* beds) and natural habitats important for fisheries, and d) reducing conflicts between different commercial fisheries.

Two types of artificial reef, protection reefs and production reefs, are used. The former seek to protect fishery resources, reduce conflicts between users, preserve ecosystems and natural habitats important for fisheries, and protect human infrastructures. The latter are deployed for increasing fish stocks and exploitable biomass by providing shelter and food, attracting marine organisms, and spatially redistributing the fish populations.

Three types of modules are usually employed: protection, production, and mixed (Fig. 2). The protection modules are concrete units heavy enough to impede illegal trawling and often provided with iron beams to entangle the nets; the production modules are bigger and have holes of different shapes and sizes to provide shelter for marine organisms, while the mixed modules combine the characteristics of the other two.

## OSPAR MARITIME AREA

**Denmark** - Two artificial reefs were deployed from 2005 to 2008 along the Danish coasts. The main purposes were the enhancement and restoration of natural habitats and species of Community interest, such as seaweed beds and cavernous bolder reefs in shallow waters, a peculiar habitat characterised by high biodiversity, which has been extensively exploited for the removal of large boulders suitable for constructing sea defences and harbour jetties (OSPAR COMMISSION, 2009).

The first artificial reef was constructed in the Vejle Fjord (on the eastern coast) in 2005 and consisted of sacks full of blue mussel shells.

In 2008 the Danish Forest and Nature Agency (Danish Ministry of the Environment) constructed the Laeso Trindel artificial reef (Kattegat) in order 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 was co-financed by the EC and consisted of the immersion of around 60,000 $m^3$ of boulders of various sizes and weights (1-6 t). A 6-yr monitoring program, including investigations before and after the boulder reef´s construction, has being carried out focusing on the following aspects: a) hydrographical conditions; b) colonization by macrophytes and benthic fauna; c) fish and shellfish fauna; d) stomach content analyses of the Atlantic cod (*Gadus morhua*) and the goldsinny wrasse (*Ctenolabrus rupestris*), and e) the behavior and migration of *G. morhua* and the European lobster (*Homarus gammarus*) by tagging with conventional t-bar tags and acoustic telemetry tags.

Another reef for research on hard substrates as a habitat for algal growth in relation to nutrient concentration is under consideration for the Limfjord (western coast).

The Ministry of Transport is the competent authority for artificial reef deployment in Denmark. No specific legislation exists but the Act for the Marine Environment covers authorizations for offshore constructions in the marine environment. An Environmental Impact Assessment is required as part of the construction phase.

**The Netherlands** - The first hypothesis regarding artificial reef deployment in the Netherlands arose in 1986, when the Dutch Working Group on Alternative Materials in Aquatic Engineering suggested the placement of an artificial reef off the Dutch coast. This idea was incorporated by the North Sea Directorate of Rijkswaterstaat in a management policy plan of 1989 and later accepted by the Dutch Government. As a result, a field experiment was set up. The reef was deployed in 1992 offshore of Noordwijk after a baseline assessment of the seabed morphology and granulometry, benthic communities and fish fauna. It consisted of four oval, 125-t mounds of basalt rock, each having a diameter of about 12 m and height of 1.5 m. The reef was monitored for five years (1992-1995) with the aim of investigating the eventual changes induced in the natural habitat and marine biodiversity (LEEWIS; HALLIE, 2000; OSPAR COMMISSION, 2009).

A new artificial reef for recreational diving is under consideration. The site has still to be decided on as well as the material to be used in its construction (OSPAR COMMISSION, 2009).

A licence for the placing of any kind of structure or material in the sea (artificial reefs included) is required in the Netherlands. This licence is granted by the Directorate of the Directorate-General for Public Works and Water Management (Rijkswaterstaat). This licence establishes severe restrictions regarding the materials to be used, as in the Netherlands it is strictly forbidden to dump chemical wastes in the sea. The licence also calls for the assurance that the artificial reef will be removed and the seabed restored, if this is requested by the Authorities, and the demand that the reef site be marked with illuminated navigation buoys for the first two years after the deployment, and that all interested parties be informed of the artificial reef´s location (LEEWIS; HALLIE, 2000).

**Norway** - Artificial reef technology in Norway is very recent and still in an experimental phase. A first small artificial reef was deployed in 2002 in Nordfjorden (southern coast of Norway), with the aim of determining the effects on flora and fauna, especially fish (Fig. 1). The reef consisted of two "Rundle reef" units each made of a central concrete

cylinder, which was filled with stone to increase its weight and stability, provided with 14 vertical rows of plastic pipes radiating horizontally outwards. Each reef unit had an overall surface area of 250 $m^2$ and weighed 9 t (Fig. 3; HARTVIG, 2007). Two other reefs, made of concrete walls and pyramids provided with holes, were placed off the Lofoten Islands in 2004 for fish attraction (Fig. 1). The most recent artificial reef was constructed in 2006 off Hammerfest (northern coast), using Rundle reefs. The purpose was the re-establishment and enhancement of kelp, other sea-weeds and associated animals (OSPAR COMMISSION, 2009).

**Portugal** - Although artificial reef deployment started later than in other European countries, Portugal is now on the way to becoming one of the most important users of this technology.

Trials on artificial reefs started in 1983 with the immersion of car bodies, tyres and wooden boats to enhance the fishery harvest off the island of Madeira (Fig. 1). Following these trials, a programme was initiated to deploy reef modules. However, the most consistent development has occurred off the Algarve coast (southern Portugal) from 1990 onwards (Fig. 1). Initially, two pilot artificial reefs were installed by the National Fisheries and Marine Research Institute (IPIMAR). The aims were to assess the environmental impact and fishing yields as well as the usefulness of artificial reefs as an instrument for managing fish stocks and increasing coastal resources.

Based on the results of these experiments, artificial reefs were recognised as a tool for the integrated management of coastal areas (enhancement of marine living organisms, improvement of fishing yields, management of coastal fisheries, habitat mitigation, etc.) and a National Programme was developed. Six new larger artificial reefs were deployed in the same area between 1998 and 2003, another having being scheduled for 2010. All the projects have been financially supported by the EC (75%) and National Government (25%).

Each reef consists of at least 2,940 small-sized protection modules and 36 large-sized exploitation units (Figs 2 and 3). Overall, the artificial reef complex will consist of more than 21,500 modules, occupying in a discontinuous way a total area of 43 $km^2$ with an estimated area of influence of around 70 $km^2$. It will likely represent the largest reef system in Europe.

Currently there is also one private initiative related to the diving industry going through the licensing process.

Each project goes through three phases: 1) site selection and reef design; 2) construction of the reef; and 3) reef monitoring and research over 3-5 yrs (a 4-yr monitoring period is required for the projects undertaken with public funds).

Site selection takes various aspects, such as the following, into account: a) evidence for the need of an artificial reef; b) absence of any negative environmental impact foreseen as resulting from the reef´s deployment; c) absence of both potential conflicts among the local users and commitments by former and future users; d) depth and substrate such as will guarantee the structural stability of the reef; e) proximity to the main users' ports; and f) depth range related to the need to protect the juveniles of the fish species usually exploited by fisheries.

Anyone may promote the deployment of an artificial reef, but the project has to be submitted for a process of evaluation involving a number of national and local authorities, users' associations, NGOs related to environmental issues, and anybody else who might also be entitled to express their opinion.

**United Kingdom** - Six artificial reefs have been constructed along the British coasts since 1984 for research on the effects of artificial structures on marine living organisms (e.g., lobsters), leisure diving, and education. Most of them are located off the coasts of England (Fig. 1).

Different types of materials and modules have been employed (Fig. 2). The first reef, made of natural rocks, was deployed off Torness (south-eastern Scottish coast) in 1984 to enhance living marine resources. It was followed by the Poole Bay artificial reef (central-southern coast of England), constructed in 1989 with experimental coal-ash blocks (Fig. 3) and implemented in 1998 through the immersion of concrete modules and tires, and by the Salcombe reef (2000; south-western coast of England) made of natural rocks. The construction of the Loch Linne reef started in 2001 and was completed in 2006. The reef complex consisted of five groups of six individual mounds of concrete blocks (JENSEN, 2002; OSPAR COMMISSION, 2009). In 2004 the HMS Scylla was sunk off Whitsand Bay (Cornwall), this was the first artificial reef of this kind in the UK. Finally, the most recent artificial reef (Bournemouth, South England) was created in 2009 for surfing tourism and consisted of geotextile bags filled with gravel and sand (OSPAR COMMISSION, 2009).

No national or regional plans for artificial reef deployment exist in the UK. Procedures are established by the local governments of England, Wales, Scotland and Northern Ireland but, in general, all artificial reefs have to be licensed and the OSPAR guidelines have to be followed.

Anyone (public authorities, private companies and/or associations, etc.) may promote artificial reef deployment and the diving industry is currently very interested. Funds may be provided by anyone the promoter can persuade to support the project.

In order to get permits/licenses to construct an artificial reef, the promoter has to submit a project plan in which objectives, site, materials and expected environmental impacts are defined with the agreement of as many interested groups as possible. Three permits/licenses are required: a) navigational consent released by the Navigation Authority; b) seabed lease to occupy an area of seabed released by the Crown Estate; and c) Food and Environmental Protection Act (FEPA) license for the actual placing of the reef on the seabed.

## BALTIC SEA

The Baltic Sea is subjected to progressive degradation mainly due to the high anthropogenic pressure associated with the particular environmental features of the area. Sewage discharges, which are generally untreated or partially treated, oil spills and accidents involving tankers, as well as fish farms, cause pollution and eutrophication leading to a deterioration of water quality and an alteration of the geographical distribution of zooplankton, benthos and finfish. (ANTSULEVICH et al., 2000; CHOJNACKI, 2000). Within this context the deployment of artificial reefs has been planned mainly as a tool for enhancing natural self-purification processes through the proliferation of sessile organisms, especially filter- and suspension-feeders.

However, the information available on the reefs deployed in this area by the different countries is scarce and, with few exceptions, is published by the European Artificial Reef Research Network - EARRN established in 1995 (<www.soes.soton.ac.uk>).

Artificial reefs have been placed by Germany in the areas off Kiel and Nienhagen, by Poland in the Odra river estuary, Puck Bay and Pomeranian Bay, by Poland and Russia in the Vistula Lagoon, by Estonia in the Gulf of Riga, and by Finland together with Russia in the Gulf of Finland (Fig. 1).

**Germany** - Two artificial reefs have been constructed since 2001, one off Kiel and the other off Nienhagen (Fig. 1). The former was constructed by a private company for research and consisted of 12 Reef Balls made of different concrete mixtures and surface textures to determine the type most suitable for the settlement of benthic organisms (<www.artificialreefs.org>).

The latter is the only reef deployed in the Baltic Sea for finfish and fishery enhancement. It is a large scale reef, placed in 2003, in the Nienhagen fishery protection zone with the aim of creating suitable habitats for juvenile fish and developing, in addition to conventional management measures (e.g. quotas, minimum landing sizes, minimum mesh sizes, etc.), alternative tools to regulate and stabilize the population sizes of economically important and endangered species. The project was funded by the EC (75%) and the German Ministry of Food, Agriculture, Forestry and Fishing (25%). Different types of concrete modules were employed: cones provided with holes, manhole rings, and tetrapods (Figs. 2 and 3; NICKELS et al., 2006). A monitoring program was carried out over 4 yrs. It focused on: a) investigations on the fish biology; b) long-term underwater video observations; c) fishing investigations; d) studies on the effects of artificial reefs on the natural habitat; e) possibilities of the commercial use of algae; f) further possible uses such as aquaculture, angling and underwater tourism, and g) evaluation of the economic aspects. The results indicated that artificial reefs could offer future opportunities for compensatory and replacement measures to make up for the loss of habitat for underwater flora and fauna caused by human activities.

The National Government is the competent authority for artificial reef deployment in Germany. The creation of artificial reefs is regulated by the Federal Nature Conservation Act, the Water Resources Act and corresponding laws of Federal States, and the National Park Law. Impact assessments are required within legally protected areas, according to EU legislation (Natura, 2000).

**Gulf of Finland** - Some pilot artificial reefs aimed at evaluating the potential contribution of these structures to the cleaning-up of the Gulf by developing additional filter-feeder communities were constructed within the framework of a co-operative agreement between Finnish and Russian research groups. The first reef modules were deployed at four sites by the Russian research group in 1992 (Fig. 1). They consisted of a steel frame provided with fouling panels made of different materials. The purpose was the study of the development and ecological succession of the benthic community (ANTSULEVICH, 1994; ANTSULEVICH et al., 2000).

A new project started in 1993 in the Archipelago Sea (south-western Finland) placed buoyed ropes attached to aluminium frames at three sites. Three experimental reefs were deployed successively at different sites off Turku, at various distances from a fish farm in order to test the influence of the nutrient output of the farm on the colonization of structures by benthic biomass (Fig. 1).

**Poland** - The planning and deployment of artificial reefs started in the 1980s with the installation of the first artificial reef in the estuary of the Odra river. In the 1990s two other reefs were deployed, one in the Pomeranian Bay and the other in the Puck Bay with the aim of creating hard substrates for the development of sessile, suspension feeder organisms (Fig. 1; KRUK-DOUGIALLO et al., 2006). The Pomeranian Bay artificial reef consisted of 12 structures made of concrete pipes and old car tyres

assembled in different shape (stars, pyramids, tunnels, etc.). Ecological investigations on the benthic colonization of the reefs carried out after their deployment evidenced a high settlement rate of filter-feeders indicating that artificial reefs might contribute to the self-purification of the sea (CHOJNACKI, 2000). In the same years another artificial reef was placed in the Vistula Lagoon in co-operation with Russia.

Three new artificial complexes, sponsored by the Ministry of Fisheries and Rural Areas Development, were planned in 2006 for the coastal zone, to enhance fish stocks. One of these involved the immersion of 50 Reef Ball modules off the Vistula mouth (Gulf of Gdańsk; KRUK-DOUGIALLO et al., 2006).

## Black Sea

The Black Sea is affected by serious environmental problems as a consequence of the high levels of hydrogen sulphide due to past geological events, eutrophication through agriculture, industrial activity and the discharge of almost totally untreated sewage, contamination through the input of harmful substances, especially oil products, the introduction of alien species, and the overexploitation of fish stocks due to unmanaged fisheries. Nearly 87% of the Black Sea is entirely anoxic.

Similarly to the Baltic Sea, in this area artificial reefs have been tested as a technology for habitat restoration through biofiltration and the enhancement of marine life.

Artificial reef construction was begun in the 1970s. Four reefs have so far been placed: one, along the Rumanian coast, one in Turkish waters and two in the Ukrainian coastal zone (Fig. 1). Used tires and concrete modules (Reef Balls) were employed (Fig. 3; ZAITSEV et al., 2002).

In addition, submerged reefs have been deployed along the Rumanian coast inside the Coastal Protection Plan for the Southern Coastal Unit developed in co-operation with the Japanese International Cooperation Agency and have a time horizon of 2020. The primary goals of the reefs are the protection of the coast from erosion and beach nourishment, but they were also planned to contribute to developing marine fauna and attracting fish (JICA, 2007).

## Conclusions

Artificial reefs in Europe have been developed over the last 40 yrs with different aims: nature conservation and restoration, fish stock enhancement, fishery management and improvement, aquaculture, research and recreation.

Fish stock enhancement and fishery management are the main goals for reef construction in the Mediterranean Sea and on the Atlantic coast of the Iberian Peninsula, while nature conservation/restoration, research, and recreation have been the main purposes in the other European regions to date.

Besides a further increase which occurred in established reef-research countries, such as Italy, Spain, and Portugal, a noticeable development is currently taking place in other States. For example, Greece has adopted a national plan for artificial reef deployment and an increasing interest in the use of artificial reefs for habitat restoration and fishery enhancement/management is also being shown by several northern European countries where this technology has so far been but little applied.

Research into scientific, engineering, legal and socio-economic aspects has contributed greatly to this success, providing a basis of information and experience which has been highly useful for a better understanding of the many challenges offered by artificial reefs for the conservation and sustainable use of the marine environment and exploitable resources (JENSEN, 2002). The European Artificial Reef Research Network (1995-1998) has played an important role in this process.

On the basis of the evidence provided by research, guidelines aimed to assist States in artificial reef construction and avoid dumping in the European Seas have been developed at international level in the last decade (OSPAR COMMISSION, 1999; UNEP MAP, 2005). Although not binding, they have been officially recognised by several States. These guidelines give an unambiguous definition of an artificial reef, thus contributing to the avoidance of past misunderstandings. Moreover, they provide for common protocols both for artificial reef deployment and the assessment of their effectiveness and impacts.

In spite of recent developments, at present national and/or regional programs for artificial reef deployment and/or inclusion of this tool in overall management plans for fisheries management and nature conservation are only in force in most countries bordering on the Mediterranean Sea, while only a few of these programs (Portugal and Spain) have been developed in the other European Regions to date. The adoption of overall regional/national reef programs is to be strongly recommended with a view to the integrated management of the coastal zones.

There is a noteworthy lack of management plans, in many countries, for the reefs after their deployment. Indeed, management measures aimed at regulating/limiting access to the reefs are essential to ensure the maintenance of reef resources over time and to avoid possible conflicts between the different users.

At the same time, research and co-operation among the researchers of different countries should continue so as to facilitate the exchange of experience and the planning of new research programs. Indeed, further research should continue to focus on the full understanding of the ecological processes associated with artificial reefs, especially in terms of fish behaviour, and how reefs can be managed so that the desired biological and socio-economic products should be obtained.

Although attitudes, requirements, and priorities may vary among countries, the key to the acceptance of the artificial reef concept still depends on research and the dissemination of the relevant knowledge to the managers of the marine environment and to users.

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