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Artificial reefs of Europe: perspective and future

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Artificial reefs have been placed in European waters for around 30 years. The majority now play a role in protecting valuable Mediterranean seagrass beds from trawl damage, and most aspire to a fisheries function. Until relatively recently, reef-building has been carried out locally, in some cases without national collaboration or international cooperation. This is changing; in 1991, Italian artificial reef scientists formed a national reef group to encourage liaison between research groups, and the Spanish created one in 1998. There is now also an association of Mediterranean artificial reef scientists. Research in Europe has reached a stage where scientific priorities for the future need to be developed in the light of previous research and experience. This is the aim, and the reason for the creation in 1995, of the European Artificial Reef Research Network (EARRN) funded by the European Commission "AIR" programme. Reefs have now been formally licensed and deployed in Finland, France, Greece, Israel, Italy, Malta, Poland, Portugal, Romania, Spain, The Netherlands, Turkey, Ukraine, and the United Kingdom, and Denmark, Ireland, Russia, and Sweden have an interest, although no specific reef structures have, as yet, been placed. Norway has deployed experimental concrete units and has an interest in the "rigs-to-reefs" concept.

Keywords: artificial reef, Baltic, Europe, Mediterranean, NW Atlantic.

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Introduction

European artificial reefs (Figure 1) were pioneered in Monaco for nature conservation purposes in the late 1960s (Allemand *et al.*, 2000). Artificial reef research programmes have now been initiated in eight countries of the European Union (Finland, France, Greece, Italy, Portugal, Spain, The Netherlands, and the UK) (Jensen *et al.*, 2000). In addition, Ireland and Denmark have indicated an interest, although no licensed structures have, as yet, been placed. Outside the EU, Norway has an interest in the "rigs-to-reefs" concept (Cripps and Aabel, 2002) and some experimental concrete units have been deployed. Poland has deployed experimental structures in the Baltic (Chojnacki, 2000). Turkey has a developing programme (Lok and Tokac, 2000). Romania (Goimu, 1986) and the Ukraine have placed some reefs for experiments into biofiltration in the Black Sea. Israel has been active in the field since the early 1980s, deploying tyre structures in the Mediterranean (Spanier, 2000) and considering reefs (Golani and Diamant, 1999) and existing structures (Oren and Benayahu, 1998) in the Red Sea. Finland is involved with developments in the Baltic in collaboration with Russia (Laihonen *et al.*, 1997) and Russia has built reefs in the Caspian Sea (SADCO-SHELF programme) (Bougrova and Bugrov, 1994). Malta has occasionally deployed ships for tourist diving since the late 1980s and is considering an inert waste-reef deployment in 2002.

As interest in artificial reefs developed, the scientists involved began to collaborate. In 1991, Italian artificial reef scientists formed a national reef group to encourage liaison between research groups, followed by Spain in 1998. An association of Mediterranean artificial reef scientists now exists. Research in Europe has reached a stage where scientific priorities for the future need to be developed in the light of previous research and experience. This is the aim, and the reason for the creation, of the European Artificial Reef Research Network (EARRN), funded by the European Commission "AIR" programme. The 51 scientists from 36 laboratories involved were all active in artificial reef research

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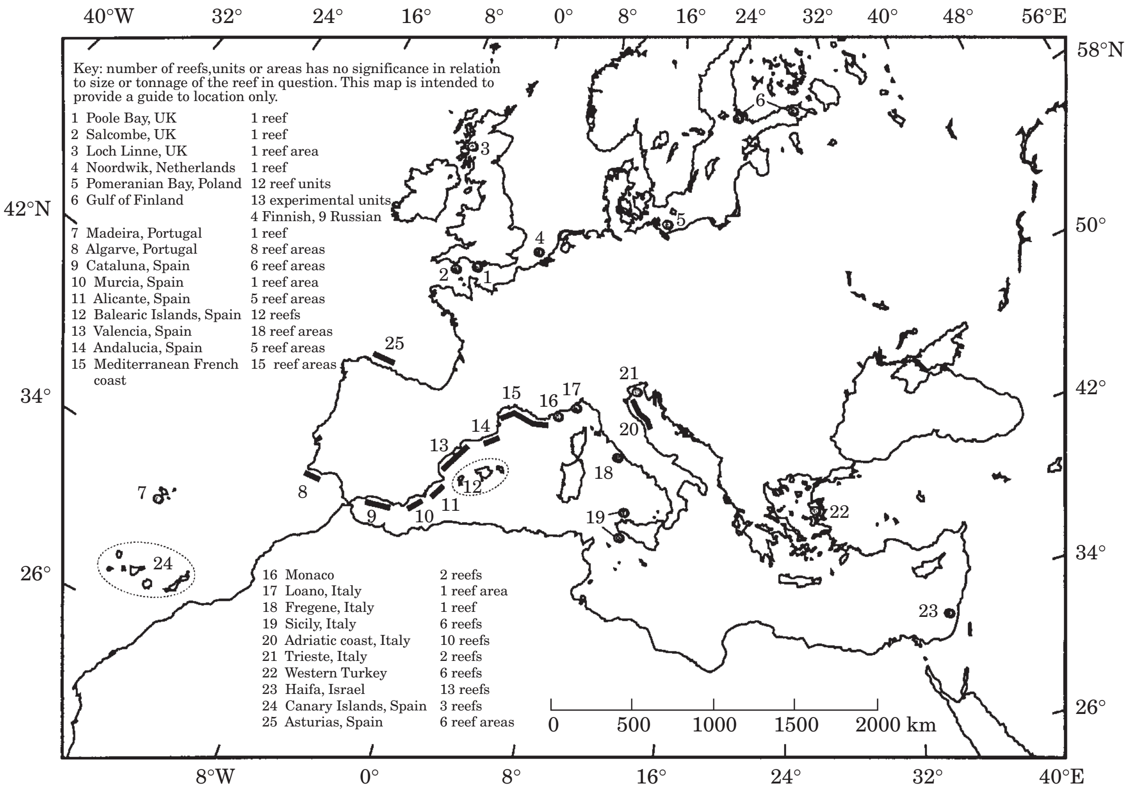

Figure 1. Locations of artificial reefs in Europe.

and the network was set up to provide recommendations for the direction of future research to the European Commission. The creation of EARRN came from an initiative at the 5th international artificial reef conference in 1991, where European scientists met informally as a group for the first time. It was (and is) felt that artificial reefs have much to offer the EU in terms of habitat management, nature conservation, fisheries management/enhancement and coastal defence, and that a network to clarify scientific issues with the following objectives would be of value: (a) to promote increased collaboration between current programmes throughout Europe (EU), both marine and freshwater; (b) to summarize results made within EU research undertaken to date and reach a consensus of opinion on given issues (c) to promote awareness of issues (socio-economic and management) within the EARRN scientific community, and encourage consideration of these aspects in developing future research proposals; (d) to produce a detailed programme of coordinated research and to identify the research groups best suited to carry out work in a given area of interest; (e) to report these findings and recommendations fully to the EC.

EARRN is still in existence and coordinated by the author. A 5-day conference in late March 1996 focused on 4 topics: management of coastal resources (including fishery enhancement), socio-economic impacts and legal aspects, research protocols, and reef design and materials (Jensen, 1997a). The meeting was followed by several topical workshops that recommended further scientific themes and actions (Jensen, 1997b,c, 1998a,b; Whitmarsh *et al.*, 1997).

Overview of ongoing programmes

United Kingdom

Four licensed marine artificial reefs now exist in the UK: Poole Bay (on the central southern English coast deployed in June 1989), Torness (off the south-eastern Scottish coast in 1984), Loch Linne (on the Scottish west coast, started in 2001), and Salcombe (southwest England, where a natural rock reef was placed in 2000).

The Poole Bay reef was deployed as a material-test experiment. The reef originally consisted of units made from blocks of stabilized Pulverized Fuel Ash (PFA), a waste material from coal-fired power stations bound with cement and aggregate and concrete control units. In 1998, tyre modules were added. The reef has been continuously monitored to investigate biological colonization and the fate of heavy metals bound within the coal. Results suggest that heavy metals are secure within the blocks, tyres are an acceptable reef material, epifaunal colonization is rapid, and that reefs do provide a good habitat for lobsters and other commercial shellfish (Collins and Jensen, 1997; Smith *et al.*, 1999; Collins *et al.*, 2001).

The Torness reef was constructed from quarried rock derived from the construction of a nuclear power station. The reef has been shown to influence local populations of cod (*Gadus morhua*) that probably use the reef as shelter rather than a source of food. The local lobster (*Homarus gammarus*) population may have been enhanced, while edible crab catch numbers do not appear to have been influenced. The presence of macro-invertebrates such as whelks, urchins, and starfish all reflect the habitat provided by the reef. The authors stress the importance of an extended survey period in assessing reef influence on catches (Todd *et al.*, 1992).

The Loch Linne reef is being constructed from blocks formed from cement stabilized quarry dust slurry, effectively recycling an inert waste material into an artificial reef. The project started to deploy reef blocks in 2001 and is planning to continue deployment over several years. When completed, the reef will have 42 000 t of material deployed in 24 modules. Research will focus on interactions between the reef structure and associated animals (with emphasis on lobsters) and plants, and the influences on the physical environment (Sayer and Wilding 2002; Wilding and Sayer, 2002a,b).

There are also interests in creating reefs for surfing and diving tourism. The first SCUBA diving reef was licensed in 2001 and will, financial support allowing, be placed close to the port of Plymouth. Interest in the decommissioning of North Sea oil rigs in such a manner as to provide artificial reefs appears at present to have been effectively halted by OSPAR guidelines in relation to living marine resources (OSPAR, 1999).

Italy

Italy has seen considerable artificial reef deployment activity. The Italians were among the first extensive users of artificial reefs in Europe and are well organized nationally. Many programmes have been assisted by 50% EU funding and both local government and fishermen's organizations are involved. Predominant projects are listed here.

Loano artificial reef

An "anti-trawling" reef system was deployed in the Ligurian Sea during 1986 (Relini, 2000a) to protect the natural environment, in particular *Posidonia* beds, from trawling gear. Trawling is prohibited in waters shallower than 50 m in the western Mediterranean (France, Italy, and Spain) and 100 m off the northern Spanish coast. Reefs have been shown to be effective in preventing illegal trawling as well as providing settlement sites for epibenthos and opportunities for colonization by fish (Relini and Relini, 1989; Relini *et al.*, 1995a, 1997).

Seasonal and successional changes of the reef communities were noted. Cement panels immersed at different depths were colonized by 117 species of sessile animals and 76 algal species (Relini *et al.*, 1994). Sixty-seven species of fish, 4 crustaceans, and 5 cephalopods were listed (Relini *et al.*, 1997), some of these utilizing the reef for reproduction. Endangered species such as groupers (*Mycteroperca rubra* and *Epinephelus marginatus*) that are rare in the Ligurian Sea were recorded in the vicinity of the reef.

CENMARE – Coal ash for artificial reefs

In the late 1980s and early 1990s, an interest developed in the constructive use of power station waste (Pulverized Fuel Ash, PFA) for reef construction in Italy. As in the UK, great emphasis was placed on the environmental suitability of such material and a large tank trial was undertaken in 1990 and 1991. Epifaunal settlement on the ash blocks proved greater in quantity and more diverse than on the control (concrete blocks; Relini, 2000b). Biomass measurements confirmed the qualitative and quantitative differences seen in the biological indices between epifaunal communities. Given the biological colonization and the physical and chemical stability, PFA was considered a suitable material for reef construction (Relini *et al.*, 1995b).

Fregene artificial reef

Deployed 9 km from the mouth of the river Tiber in the central Tyrrhenian Sea in 1981, this reef is subject to severe siltation and has been studied primarily to gain an insight into the way fish and epifaunal communities change over time and with environmental conditions (Ardizzone *et al.*, 2000). Over 11 years of study, the fauna changed from a pioneer community to a mussel-dominated community, followed by a temporal decline (Ardizzone *et al.*, 1996) as siltation prevented further settlement. Mussel disappearance was linked to a reduction in numbers of fish species (Ardizzone *et al.*, 1997) and the surfaces developed an infaunal population (Somaschini *et al.*, 1997). The development of the sediment community is considered to be a key point in the evolution of the reef, as mussels could no longer settle onto a surface they had once dominated.

North-west Sicily (Gulf of Castellammare, Gulf of Palermo, and Bay of Carni)

These reefs have been placed from 1982 onwards and Riggio *et al.* (2000) have evaluated benthic and nektonic colonization, fishing yields, and trophic relationship between resident fish and benthos in the reef area. Benthic settlement was strongly influenced by water quality ranging from oligotrophic to turbid/eutrophic (D'Anna *et al.*, 2000). The differences were most pronounced in algal cover, which was high in oligotrophic waters while being non-existent in the turbid waters. Number of species and species diversity in the nekton assemblage was higher in the reef area than in control areas (D'Anna *et al.*, 1994) also, fishing yields were slightly higher (Arculeo *et al.*, 1990). Stomach content analysis revealed that Sparid fish preferred feeding around the reefs rather than on natural substrata (Pepe *et al.*, 1996).

Adriatic Sea

At least 11 artificial reefs exist along the Italian Adriatic coast (Bombace *et al.*, 2000). Seven of these (Cattolica, Porto Garibaldi 1, Portonovo 1 and 2, Porto Recanati, Rimini, Senigallia) serve as the best European examples to date of reefs that have provided successful commercial harvests, especially of bivalves, and that are used both by fishermen and aquaculturists.

The Porto Recanati reef, deployed in 1974, was the first Italian reef to be scientifically planned (Bombace, 1989). The aims of the scheme were: protection from illegal trawling, re-population of biota through the provision of habitat, and development of new, harvestable sessile biomass, especially mussels and oysters, through the introduction of suitable surfaces. The initial costs were recovered three times over in about 4 years through small-scale fisheries and collection of the mussels settled on the artificial substrata (Bombace *et al.*, 1994).

Portonovo 1 was used for experimental work on suspended shellfish culture (mussels and oysters; Fabi and Fiorentini, 1997; Fabi *et al.*, 1986). Those at Porto Garibaldi (1 and 2), Rimini, Cattolica, Portonovo (2) were deployed in 1987–89 on behalf of local fishermen's associations and represent large-scale commercial systems with the aims of prevention of illegal trawling, re-population, and mariculture. At these sites, fishing surveys with a standard trammel net were started one year before reef deployment and continued for a few years after so that their effectiveness in terms of fishing yield and their impact on the fish assemblage of the original habitat could be compared.

The overall scientific results can be summarized as follows:

(a) Species richness, species diversity, as well as fish abundance increased after reef deployment (Fabi and Fiorentini, 1994), particularly for reef-dwelling nekto-benthic species (e.g. Sparids and Sciaenids). The increase in average catch weights recorded for these species 3 years after deployment were 10–42 times the initial values. The increment seems to be directly correlated to reef dimension in terms of volume of immersed materials and inversely correlated to the distance between the oases.

(b) Higher catch rates of reef dwelling fish were reported from the reefs in comparison with unprotected areas (Fabi *et al.*, 1999).

(c) The fish assemblage at the reefs fluctuated seasonally. The lowest numbers and diversity were generally recorded in winter, when most of the species migrate to deeper, warmer waters (Fabi and Fiorentini, 1994).

(d) Fishery resources seem to be "buffered" against significant reduction compared to stocks in areas without reefs (Fabi and Fiorentini, 1993).

(e) In eutrophic waters, the annual settlement of bivalves on the structures provides mariculture opportunities for coastal communities. Annual production was measured as 8 kg mussels m^{-1} rope (Fabi and Fiorentini, 1990).

Gulf of Trieste

Concrete pyramids deployed off the site of the Marine Biology laboratory at the University of Trieste in 1988 have been studied to provide data on settlement and colonization of periphyton and other ecological parameters (Falace and Bressan, 2000).

Monaco

Reef deployment started in 1979 in the Undersea Reserve of Monaco, an area close to the shore that was protected in 1976 to halt the progressive destruction of the *Posidonia* meadow (Allemand *et al.*, 2000). The units have been colonized by sediment-tolerant epibiota (Balduzzi *et al.*, 1986) and a fish fauna typical of a shallow rocky Mediterranean reef. Fish numbers increased when reef units were clustered together rather than being placed in relative isolation (Barnabé and Chauvet, 1992).

A second reserve area was designated in 1986 to protect the only coral slope in the Principality providing a focus for the development of artificial reefs for red coral (*Corallium rubrum*) cultivation (Allemand *et al.*, 2000; Debernardi and Allemand, 1993). Concrete caves were deployed in 1988 (Debernardi, 1992). Red coral was transplanted from the natural slope population (Cattaneo-Vietti and Bavestrtrello, 1994) and survival was maximized when an epoxy resin was used to attach the coral to the cement cave walls. A later design, using glass fibre, to improve water circulation inside the cave as well as providing better diver access to the corals was deployed in 1993 (Allemand *et al.*, 1995).

France

Activity started in the late 1960s and early 1970s on both Atlantic and Mediterranean coasts, initial structures being made from old car bodies and tyres. While tyres were used in later Atlantic reefs, concrete became the construction material of choice in the Mediterranean. Much of the deployment in the last 20 years has focused on the Mediterranean coastline, with 14 reefs, some 39 000 m^3 of material, now in place (Barnabé *et al.*,

2000) to protect habitat and develop local fishery interests, although regional interests are also served.

Following pilot experiments, 18 000 m^3 of reef materials were deployed in five reefs off the western coast (Languedoc–Roussillon region) in 1985 to protect static fishing gear and longlines from illegal trawling as well as promoting marine life. Natural rock and concrete-armed pyramids were used in construction. Extensive colonization by oysters, fish and lobsters on some reefs was reported by Tocci (1996).

The reefs on the eastern coast (Provence–Alpes–Côte d'Azure region; >19 000 m^3) focused on *Posidonia* restoration following damage from coastal developments and on restoration of rocky reef species. Research concentrated on the development of fish assemblages (Ody and Harmelin, 1994; Charbonnel, 1990). The artificial reefs provided effective fish habitat, sometimes holding more fish than comparable natural reefs. The greatest number of fish have been recorded where small modules (1–2 m^3) were placed in chaotic heaps of 100 m^3 or so (Charbonnel, 1990; Charbonnel *et al*., 2000).

Portugal

Two programmes have started, one off the island of Madeira and one on the mainland. The Madeira reefs are in a developmental stage. Trials starting in 1983 used car bodies, tyres, and wooden boats to enhance fisheries harvest. A programme has been initiated to deploy reef modules following baseline assessment of fish diversity and biomass.

On the mainland, research initially concentrated on a pilot programme with two reefs off the Ria Formosa, an important estuarine system on the Algarve coast near Faro. The aims were to evaluate the impact at the ecological level and in terms of fishing yield, and to determine their usefulness as an instrument for fish stock management and for increasing coastal resources. The experiment consisted of two reef types: a "production reef" and an "exploitation" reef. The production reef (735 concrete lattice units each 2.7 m^3) was deployed to provide shelter for juvenile species migrating from the lagoon to open coastal water. The exploitation reef (20 concrete structures in two sizes, 130 m^3 and 174 m^3) was placed further from the lagoon mouth to aggregate fish (Neves dos Santos and Costa Monteiro, 1997). The structures were successful in that they were physically stable, developed an epibiotic community within months, and concentrated fish (Neves dos Santos and Costa Monteiro, 1998; Costa Monteiro and Neves dos Santos, 2000).

The results have led to the development of a much larger reef system for commercial exploitation, which should be fully operational by the end of 2002. This complex will involve a 35 km^2 area of seabed off the Algarve coast, using more than 19 000 modules with a combined weight of 66 690 t, and will be the largest artificial reef system in Europe. The primary focus is on increasing and diversifying fishing yield, but the structures are also expected to increase epibiotic biomass and diversity in the area and may provide a focus for recreational diving as well as sites for research (Costa Monteiro and Neves dos Santos, 2000).

Spain

Extensive reef-building activity throughout Spain and its islands is coordinated by national government with considerable input from local government (Revenga *et al.*, 1997) and 50% funding from the EU in most cases. At least 57 reefs have been constructed in Spanish waters, some several km^2 in area, mainly with habitat protection (anti-trawling) and/or artisanal fishery enhancement as the main aims. Not all reefs are subject to scientific monitoring but three areas are worthy of note.

Balearic coastal waters

Reefs were deployed around the islands of Minorca, Majorca, Ibiza, and Formentera between 1989 and 1991 to enforce anti-trawling legislation and to examine their fisheries enhancement potential. Scientific evaluation involved assessment of the colonization by benthic organisms and the presence and abundance of nektonic species around the reefs (Moreno, 2000).

Fish communities formed around the reef units in the first 12 months after deployment and remained relatively stable thereafter. Groups such as Labridae, Mullidae, Sparidae, Serranidae, and cryptic groups such as Blennidae and Gobidae, increased significantly from the baseline state (Moreno, 2000). In seagrass areas, fish communities established sooner and species were more abundant and varied than those seen around modules on sand.

Reef epibiota developed in phases: 6 months after deployment, blue geen algae and stoloniferous hydroids and bryozoans were present; after 10 months the abundance of these species had increased; and by 18 months the community provided 100% cover and included vertical forms of hydroids, sponges, encrusting bryozoans and ascidians (Moreno, 2000).

The success of reefs as a physical obstacle to trawling appeared to be only partly achieved. Degraded seagrass areas did not show further signs of damage but they did not regenerate. The size of the units (1.69 × 1 m cylinders with 4 protruding iron spikes), used solely to deter illegal trawling, made them easy to detect with echosounders, but at least one net was snagged and damaged (Moreno, 2000).

El Campello and Tabarca Island (Alicante)

Baseline surveys in the waters off the SE Iberian peninsula showed that up to 48% of some *Posidonia* *oceanica* meadows showed signs of mechanical damage by trawls (Sanchez-Lizaso *et al.*, 1990). Extensive reef fields were considered to be the most promising approach to deter illegal trawling in the marine reserve of Tabarca and off El Campello. Initially, solid 1.5 m^3 concrete cubes (8 t) were used, but these were modified later to provide hollow units with an internal core filled with pipes and bricks to increase niche diversity. To increase the deterrent effect, 5 (0.5 m long) steel beams projected from their sides. The fields were planned to maximize deterrence with a minimum number of units and this has worked with no illegal trawling being seen at the Campello reef (358 blocks, in 47 squares, protecting 5 400 000 m^2) since deployment in 1992 (Ramos Espla *et al.*, 2000).

Monitoring of the meadows following reef deployment was focused on seagrass, the bivalve *Pinna nobilis*, and the red mullet (*Mullus surmuletus*), and a general census of the fish population around the units. In the Tabarca reserve, *P. oceanica* shoot density had increased from 10 to 60 shoots m^{-2} in 1998 (6 years after deployment). In the Campello reef area, *Pinna* had been effectively absent, while 18 months after deployment a juvenile population was recorded at a density of 0.02 individuals m^{-2}. Population densities of fish species varied in their response. For example, *Diplodus vulgaris* was present at densities 3–5 times higher around the reef units than in the meadow, while *Diplodus annularis* showed no significant differences. Numbers of red mullet did not change following reef deployment (Ramos Espla *et al.*, 2000).

Canary Islands

Both artificial reefs and fish-attracting devices have been deployed around the Canary Islands. Most scientific data come from a reef deployed off Gran Canaria in 1991 in Santa Agueda Bay, following baseline surveys in 1989 (Haroun *et al.*, 1994). The reef comprises 84 concrete modules (in 5 designs; range 2–14 t, 2–36 m^3) over an area of 24 000 m^2. Post-deployment surveys (14 months) showed that fish from nearby natural reefs had colonized the structures and that a diverse epibiotic community had developed. Pelagic fish were observed feeding around the modules (Haroun and Herrera, 2000). Surveys after 30 months showed a different picture: a ‘‘bloom’’ of *Diadema antillarum* (long-spined sea urchin) had grazed the cover substantially and Shannon–Wiener diversity index values for epibiota had decreased from a peak of 2.3 to 0.25 (Haroun and Herrera, 2000). The cause of the bloom has not been established.

Israel

The first experimental tyre reefs were deployed in the Mediterranean in 1982, but following severe damage during winter storms, design and engineering were revised. Modified used-tyre units placed in 1983 were joined by a large barge later in the year and finally with three smaller barges in 1992. Research focused on fish and macro-invertebrate colonization. Species composition was similar to that found on the low-profile, biogenic reefs typical of the continental shelf of northern Israel (Spanier *et al.*, 1989, 1990) with 82% of the 43 fish species being found in both habitats. Commercial species recorded included grouper, seabreams, and slipper lobsters (*Scyllarides latus*). Lessipian migrants featured in the surveys, contributing 13.5% of the species in 1985 (Spanier *et al.*, 1990).

Slipper lobster were first seen in the tyre reef complex in 1983 and developed a seasonal pattern of abundance, being present in greatest numbers between January and June (Spanier and Almog Shtayer, 1992). They foraged on bivalves during the day, sheltering at night preferably in smaller reef holes and horizontal crevices. The lobsters appeared to be gregarious (Spanier *et al.*, 1988). The physical stability and biological success of these structures has led to consideration of reef developments for fisheries and recreation. In addition, the possible use of waste materials such as cement-stabilized coal ash is also being considered (Spanier, 2000).

The Netherlands

In September 1992, an experimental reef consisting of 4, more or less circular, 125 t heaps of basalt blocks (20–80 cm diameter) in a row perpendicular to the prevailing current direction was placed 8.5 km off the Dutch coast at Noordwijk. Each sub-unit was about 1.5 m high and about 10 m in diameter (Leewis and Hallie, 2000). The aims of the project were to investigate rate of epibiotic colonization and possible effects on the morphology of the surrounding sea bottom and biomass distribution. Fish and benthic fauna in the area were assessed before the reef was placed. Species composition and biomass on the reef and in the surrounding area up to 1 km distance were monitored 5 times per year. The physical stability of the construction was also monitored. The reef showed a steadily increasing biomass and diversity of typical North Sea fauna until the end of 1996 (Leewis and Hallie, 2000), when the programme was halted based on a political decision in response to reactions from shrimp fishermen and the public.

Finland

A reef programme started in late 1993 and was linked to the problems of managing fishfarming waste. The main aim was to assess whether growth potential of fouling communities in the Finnish Archipelago (Gulf of Bothnia) was sufficient to remove nutrients (directly or indirectly) released by fish farms. Cage farming is an expanding industry in the area and nutrients released by overfeeding and faeces are causing eutrophication. Different materials and structures were tested as substrata for filamentous algae and epifauna (Laihonen *et al.*, 1997). Recruitment, growth rate, and the efficiency of up-take of nutrients by the fouling communities were recorded. Algae formed the majority of the fouling community. According to mass balance calculations, the nutrients absorbed were not sufficient to reduce the excess nutrients significantly (Antsulevich *et al.*, 2000).

Poland

Work to combat effects of eutrophication has also been undertaken in the southern Baltic (Pomeranian Bay). Pilot experiments suggested that increasing the volume of hard substrata in the area would promote epifaunal biomass and increase "self-cleaning" in the Bay through filtration and sediment accumulation. Deployment of 23 000 m^2 of concrete and tyre reef surfaces in 1990 developed a cover dominated by *Mytilus edulis* and *Balanus improvisus*. Colonization rates were high: up to 400 000 individuals m^{-2} were recorded after 145 days. Although density decreased with time by a factor of 10 after 1204 days, reflecting the growth of mussels and barnacles, Chojnacki (2000) considers that the reefs are contributing to the "clean up" of the Bay by providing an additional epifaunal community.

Turkey

Following several unmonitored reef deployments by diving groups and universities, the first reef deployed with a scientific programme in place was located off Hekim Island in 1991 to study its impact on fish populations. Both species number and number of individuals doubled following deployment, with variations among seasons and between units placed at 9 and 18 m depth (Lok and Tokac, 2000). Research is being continued and government guidelines have been drawn up to regulate construction and deployment practices. More reefs have been, and will be, deployed for coastal management of fishery resources, habitat (seagrass) protection and scientific research.

Perspective and future developments

Perspective

Reefs in Europe have developed over a 30-year period from interesting, small nature conservation projects to major programmes aimed at developing and sustaining regional fisheries with a variety of other positive outcomes. Engineering, legal, economic, and scientific researchers have contributed to these successes and have provided a basis of information on and experience with reef design in relation to ultimate goals, which can be readily used in future developments. Different countries and regions have very different needs and approaches to the use of artificial reefs. For example, the use of large reef fields (mostly several km^2) in the Mediterranean Sea to support existing anti-trawling legislation is not seen in northern Europe, partly because such legislation does not exist. This diversity in applications creates many challenges for the artificial reef research community in the coming decades.

Artificial reefs are still seen by most managers of the marine environment and/or fisheries in Europe as an ineffective and expensive technology. The concern is frequently voiced that reefs will only attract and concentrate fish and so contribute to overfishing. The diversity of its potential uses (such as protection of benthic spawning grounds) in combination with complementary legislation to direct fishing effort has yet to be understood by many of these managers. Scientists will have to show how reefs can be used to provide sustainable fisheries before they will be more commonly applied in European waters. The Adriatic experiences have shown that reefs can be used profitably for mariculture and the large-scale Portuguese deployment of reefs for fin-fish fisheries will provide data to elucidate how they can best be used in this role. Initiatives such as the Loch Linne reef in Scotland will expand the knowledge required for promoting crustacean fisheries.

So far, reefs are more frequently used to protect habitat (mostly seagrass meadows) than for anything else, yet this aspect is not widely acknowledged and only highlighted within the scientific literature. The application of reef technology to nature conservation issues needs to be emphasized as its potential for habitat development and protection is high. Other uses may also develop. The transfer of surfing reef technology from Australia to the UK may be a step forward. Hybrid structures combining coastal defence with habitat enhancement are welcome in northern Europe as engineers strive to increase the environmental value of standard structures.

The investigation into environmentally acceptable waste materials may well serve to reduce building costs and resolve recycling issues in the terrestrial environment. Much hearsay circulates about the environmental impact of alternative reef materials such as used tyres, and scientific assessment is needed to provide fact rather than fantasy.

Future of artificial reef research in Europe

Effective, purposeful reef design will be one of the most important research topics of the future. Understanding the requirements of a variety of species with outstanding commercial and/or conservation value will become more important as managers develop an increasingly holistic

Table 1. Summary of future research topics recommended by EARRN.

Aquaculture	A1	Development of reef-based coastal systems
	A2	Socio-economic analysis of developing projects
	A3	Development of equipment and methodology
Ranching	R1	Understanding of habitat requirements
	R2	Reef design
	R3	Economic appraisal
	R4	Legal assessment
Biomass production	BPI	Survival of juveniles
	BP2	(linked to BPI) Food availability and value
	BP3	Energetic advantage
	BP4	Scale of habitat
Fisheries	F1	Exploitation strategies
	F2	Protection of habitat
	F3	Resource partitioning
	F4	Impact on existing fisheries
Reef system	RS1	Attractiveness to fish and other mobile species
	RS2	Predicting performance
	RS3	Energy flow
Monitoring and appraisal	MAI	Socio-economic and technical performance
	MA2	Proposed EARRN monitoring programme in the field
	MA3	Physical, biological and chemical parameters around reefs
Recreation and tourism	RT1	Design to meet needs of user community
	RT2	Socio-economic benefits
Materials	M1	Scrap tyres
	M2	Shipwrecks
	M3	Re-use of steel jackets from oil production platforms
	M4	Development of concrete mixtures
Reef design	RD1	Prevention of trawling and/or encouragement of other gear
	RD2	Availability of food species (sessile or mobile)
	RD3	Provision of specific habitat
	RD4	Promotion of tourist benefit
Nature conservation	NC1	Biodiversity development
	NC2	Scale – how big to have a measurable impact?
	NC3	Environmental assessment

approach to fisheries and nature conservation within the coastal zone. New applications may be expected in areas where reef-based SCUBA diving, angling, or surfing can be developed. Reefs may also have a part to play in coastal protection, reducing wave energy in shallow water. The socio-economic benefits have yet to be fully assessed (Whitmarsh, 1997), but diversification of income sources for coastal fishing communities appears to be a sensible goal.

The problem of scale in relation to functionality of artificial reefs has yet to be addressed. How large has a reef to be if it is to function as a self-sustaining ecosystem? We are aware that so far structures have not reached that scale. The recent deployments off Portugal and Scotland are becoming larger and will contribute to the much-needed research to establish the effective size relative to accomplishment of specific aims. Japan (world leader in reef technology to generate seafood harvests) use reef units in multiples of 2500 m^3 within local community, artisanal fishery areas, and multiples of 150 000 m^3 within regional reef development programmes (Simard, 1995).

Currently, engineering and science continue to develop. Greece deployed its first major reef in 1998. Denmark is considering reefs for habitat replacement and taking the reef effect of rock scour protection around marine windfarm pylons seriously. Tunisia is becoming interested as well. The established reef-research countries are also pushing ahead with new ideas for aquaculture, habitat design and protection, tourism and uses for scientific experiments. All these activities are aimed at gaining a greater understanding of how reefs can be used as an integrated management tool within the coastal zone. The EARRN (Jensen, 1998b) outlined research topics considered important in future research proposals (Table 1).

Many of these aspects interrelate and any single research project would involve a variety of topics. Future research should seek to produce quantified, comparable data that will lead to the construction of carefully planned, targeted, designed, and assessed artificial reefs. Their development should involve socio-economists, engineers, scientists, and local communities and users as well as those with responsibility for coastal management. For future progress, researchers must strive to reveal how reef systems work and how they may be manipulated to provide desired biological and socio-economic end products. Artificial reefs are being widely applied in Italy, Portugal, and Spain, but there is some way to go before they are accepted throughout Europe as effective and responsive tools in coastal habitat management. While national attitudes, requirements, and priorities will vary when it comes to the uses that artificial reefs are put to, the key to acceptance is the effective dissemination of knowledge gained through good quality research.

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