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ABSTRACT

Floating artificial structures called "Kannizzati" have been used since time immemorial in the Mediterrancan Sea, mostly in the southern basin (Sicily Malta) for so-called "fishing-in-the-shade." First experiences with man-made reefs in the Mediterranean Sea (Italy, France, Israel) date to the early 1970's. The first scientifically directed artificial reef was built in 1974, in the Adriatic Sea, with stones and concrete blocks. Subsequently, old ships were sunk in the same area and mussels were cultured on ropes suspended from iron frames. In Italy, artificial reefs built on soft bottom in near-shore areas are multipurpose mechanical structures to prevent illegal near-shore bottom trawling, to provide refuge for marine species, and for mariculture of suspended mussels in unsheltered areas of high primary productivity.

Artificial Reefs and Mariculture Along the Mediterranean

The continental shelf of the Mediterranean is not as broad as in other places around the globe. Generally, it extends 3 miles from the coast or to the 50-m isobath. Trawl fishing is forbidden within these limits; but within this area, other gear and user group conflicts arise. Demersal resources show signs of overfishing by catches represented mainly by 0+ and age 1 year fish. In recent years, in certain areas of the Adriatic, lower Thyrrhenian, and southern Sicily, the demersal and some of the pelagic stocks have shown signs of reduced biomass. There is also evidence of increased nutrient load contributed to the inshore waters by the Mediterranean industrial countries. This needs to be recycled. Artificial reefs and related forms of mariculture can contribute to solving some of the above-mentioned problems.

Many authors (Buchanan, 1972; Stone and Parker, 1974; Liao and Cupka, 1979) define artificial reefs as objects made by man, or natural objects, placed in selected zones for the purpose of creating and improving the habitat and, therefore, increasing productivity and harvests of desirable species.

There is no doubt that ties exist between artificial reefs and open-sea mariculture. Italian experiences show that artificial reefs support shellfish culture and within artificial reef protected zones, suspended farming activities can be created. Also floating artificial structures can serve as supports for the settlement of "seed" of mussels, oysters and similar bivalves thus furnishing a supply of seed traditional shellfish farms. The floating shellfish farming structures additionally serve as trophic attractors for different fish species.

French experiences with artificial reefs date from 1982 and are oriented towards preventing illegal trawling and to attracting and concentrating fish and fauna. Different ecological ideas are behind these projects, hence different technologies are used, but with a common goal: to improve small-scale, local fisheries by increasing income and stimulating development of fishery cooperatives (self-managing restricted areas). Different technologies are employed according to the objectives desired. Scientific and technological investigations continue. Small volume, local commercial fishermen are very interested in obtaining concessions to build new artificial reefs and authorities are looking favorably upon these requests in a more concerted effort to manage coastal resources and control fishing effort.

Historic Development of Artificial Reefs.—Floating Structures. Floating fish aggregation devices called "Kannizzati" (in Maltese) or "incannizati" (in Sicilian)

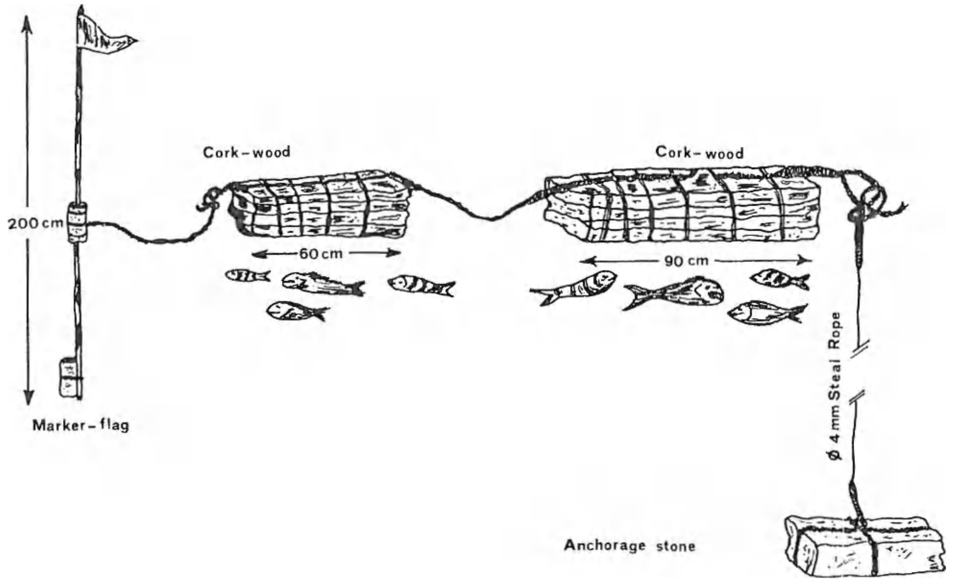

Figure 1. Floating fish aggregating devices "Kannizzati." These are intended to provide shade for fish. Used in the southern part of the central Mediterranean, Malta, and Sicily (from Galea, 1961, modified).

have been used since history began in the southern part of the central Mediterranean basin (Malta, Sicily) for so-called "fishing-in-the-shade." The floating part (Galea, 1961) consists of two large tubular masses of cork in layers connected to each other by a cable. This connecting cable has a signal flag at one end and a large stone or an anchor on the other (Fig. 1). In the summer–autumn period, some species such as dolphin fish (*Coryphaena hippurus*), pilot fish (*Naucrates ductor*), amberjack (*Seriola dumerili*), and others take refuge in the shadow of these floating bodies. Such fish are caught either by a seine or a long-line, depending on the conditions of the sea and the concentration of fish around the Kannizzati. Other surface or sub-surface floating structures (Fig. 2) are used in coastal waters to culture mussels and oysters (and also for harvesting seed) by various Mediterranean countries (France, Spain, Italy) and in the Black Sea (Bulgaria) (Popov and Zlatanova, 1986). Even if the fundamental purpose of these structures is bivalve farming, when mussels and oysters are established on cables they tend to attract and concentrate different nektobenthic fish (gilthead, sea bream, meagre, white sea bream, saddled bream, sea bass). These floating systems of molluscan culture may or may not be associated with fixed artificial reef structures.

Other countries, such as Greece and Algeria, are beginning to adopt these floating techniques of molluscan culture. Yields of mussels from open sea floating systems in the Mediterranean approximate 6,000 tons/year.

Bottom Structures. Before the 1970's, some artificial reefs in the Mediterranean were car wrecks installed in limited zones, basically to counter illegal trawling. These instances were not supported scientifically (for example, Palavas in France, Varazzi in Italy). However, in 1974, the first scientifically planned artificial reefs were begun in the Adriatic, under the Marine Fisheries Research Institute (I.R.PE.M.) of the National Research Council (C.N.R) in Ancona, using concrete blocks assembled in pyramids with 14 elements, stones, and some old

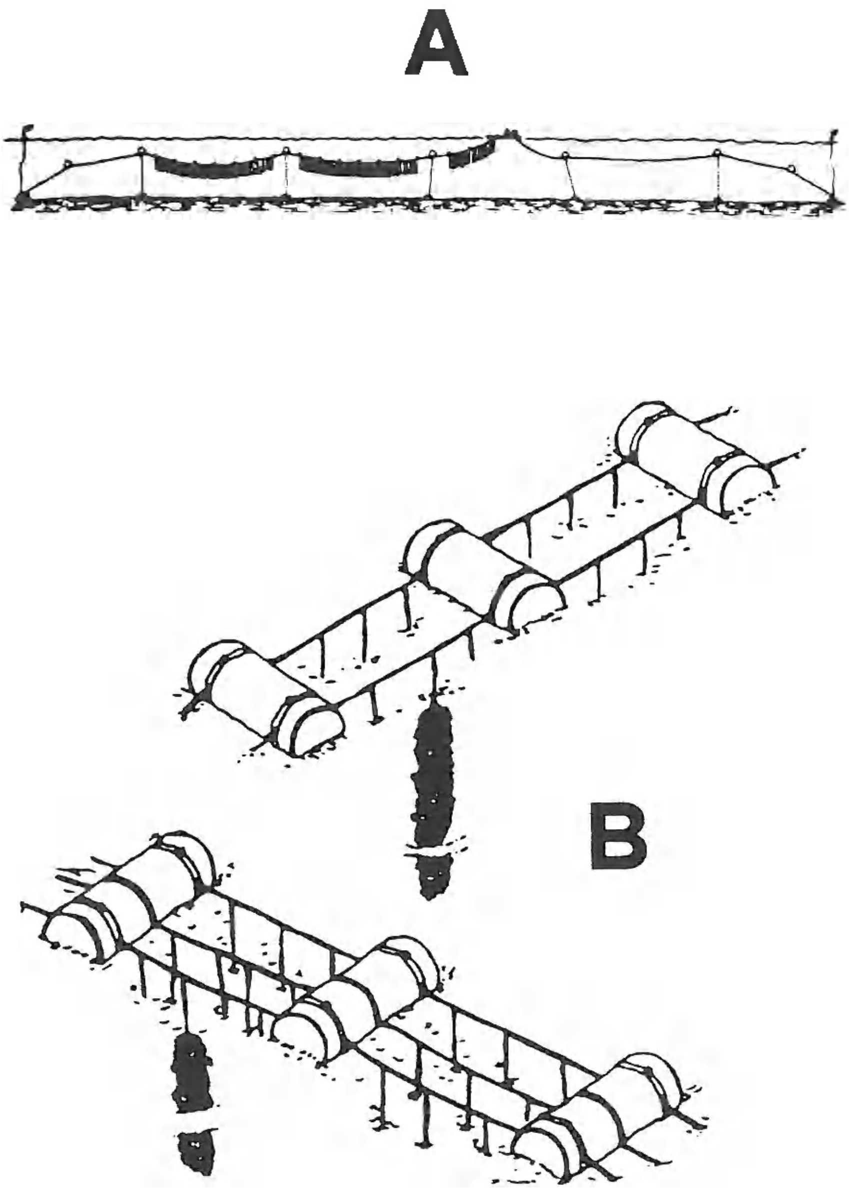

Figure 2. Artificial floating structures used in the Mediterranean sea for mussel culture: A, Subsurface long-line used in the French coastal zone (from Vidal-Giraud, 1986); B, Surface structures with two or three suspended long-lines used in Italian bays, Gulf of Trieste and Gulf of Mandredonia (from Bussani, 1983, modified).

boats (Bombace, 1977; 1981; 1982; 1983) (Fig. 3). Subsequently, other initiatives were completed in Italy and still other multipurpose artificial reefs are under construction. These reefs include those used for suspended and submerged mussel mariculture in the Tyrrhenian and in the middle Adriatic. In the Ligurian Sea (Marconi Gulf) an artificial reef was completed between 1980–1985. It consisted

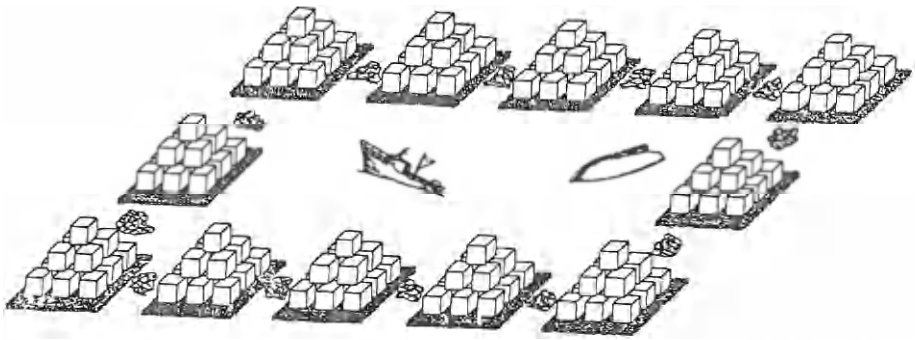

Figure 3. Diagram of the reef zone built southeast of the Conero promotory (Middle Adriatic Sea) by the Marine Fisheries Research Institute (from Bombace, 1981).

of 1,600 m^3 of material, including dock-gates, lighters, concrete blocks, and other materials (Relini et al., 1986). Initiatives using blocks and other forms of concrete are underway in Sicily (Province of Palermo, Gulf of Castellammare, Province of Agrigento).

France has made several experimental attempts to build artificial reefs. At Palavas-les-Flots (1968) car wrecks, old tires, and 1-m^3 concrete blocks for a total volume of 400 m^3 were submerged. In Concarneau from 1970–1973, 200 m^3 of blocks and tires were sunk. There were other minor experiments at Arcachon (1972), Beaulieu-sur-mer (1972) and Giens (1973).

Beginning in 1980, the most outstanding experiment in artificial reef technology in the Mediterranean was begun. Off Nice, in the Gulf of Juan and Villefranche-sur-mer, 2,000 m^3 of concrete modules have been submerged, with old tires and construction materials (Lefevre et al., 1984; Duval and Duclerc, 1986). In 1980, at Port La Nouvelle, 3,000 m^3 of material consisting of tires and concrete cylinders was submerged. Finally, a scientific research project using artificial reefs for fishery management is underway in the Languedoc-Roussillon zone. Five sites are being studied and two types of concrete modules (Fig. 4) with total volumes of 1,216 m^3 to 6,688 m^3 have been submerged. In the Principality of Monaco in a marine reserve, structure of concrete bases and perforated bricks have been submerged and assembled for repopulation and study. As a result, there is no illegal trawling in this area.

In Spain, an artificial reef project is being planned for the marine reserve of the Island of Plana or Nueva Tabarca (zone of Alicante). It is an experimental, multipurpose reef designed with antitrawling modules and modules for attracting and concentrating fish.

Current State of Artificial Reef Programs.—Basically, the use of artificial reefs in the Mediterranean is still in an experimental stage and is limited to a few coastal areas. At present, there are no national programs of broad scope aimed at managing fishing. In Italy, projects have been completed, promoted either by scientific institutions or by certain public groups or, more recently, by fishermen's cooperatives, in accordance with EEC regulations which provide financial assistance.

Project Objectives. Mediterranean projects have many and varied objectives, such as the following: (a) Protection of coastal environments (nursery areas) or of some particular biotopes (Posidonia beds) from the impact of illegal trawling, hence reducing fishing mortality in the area and increasing the biomass of native

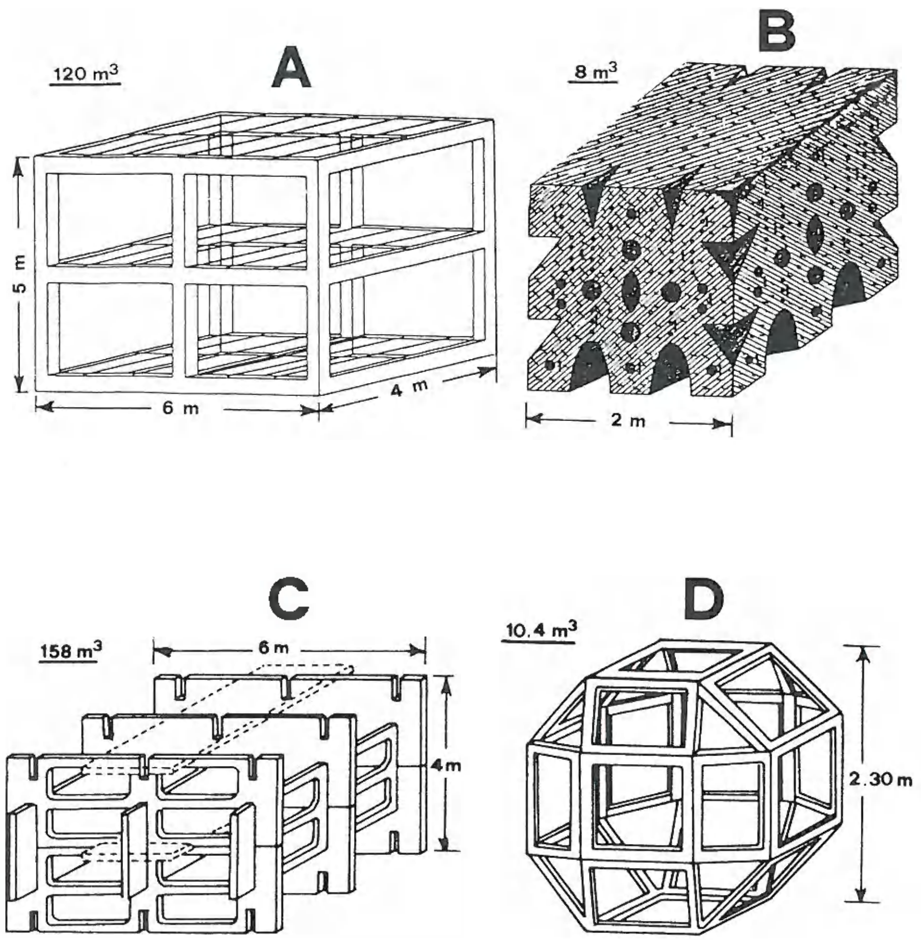

Figure 4. Modules used in Mediterranean Sea for building artificial reefs: A, Concrete cage used in Italy within the reef area for mussel culture and attracting fish; B, Concrete block used in Italy assembled in pyramids for multipurpose artificial reefs; C, D, Concrete modules used in France (from Duval and Duclerc, 1986).

species. (b) Attraction, concentration, and shelter for pelagic, nectobenthic, and demersal species of economic importance that have ties with hard substrate. (c) Increasing benthic biomass by colonizing hard substrate; providing protection and refuge for eggs, embryo sacs, and small invertebrates; creation of ecologically diversified habitats and niches; creation of new trophic networks. (d) Recycling, through shellfish farming, associated with artificial reefs, wastes and energy surpluses which are concentrated in some coastal areas. This last objective can be carried out with special artificial reefs in high-energy, shallow coastal waters (eutrophic environments). The basic purposes of these initiatives are to: (1) increase the production of coastal ecosystems, (2) manage resources more efficiently by controlling fishing effort and water spaces, and (3) enable small scale commercial fixed-gear operations to recover.

MATERIALS AND UNITARY MODULES. The primary materials for reef construction have changed since the beginning when car wrecks, tires, and other materials were used. Now projects are oriented towards using concrete forms. Italy uses mainly concrete blocks, measuring 8 m^3 and weighing 13 tons each (Fig. 4), assembled to form pyramids of 14 or 15 elements. These blocks are designed with holes and cavities of different shapes and sizes to create shelters and niches for various species. The top blocks of the pyramids have supports for attachment of cables for mussel culture, when the reefs are established in eutrophic waters. These blocks have multiple functions consisting of: (a) formation of new biomass, (b) diversification of trophic web, (c) attraction and refuge, and (d) mariculture.

Smaller blocks, old boats, and lighters have been used in the Ligurian Sea. Concrete cylinders and stones have been used, among other things, as integrative materials. Parallelepipeds have been employed to prevent illegal trawling. These are made of concrete, filled with concrete, and spanned by pieces of iron beams or concrete crosses, connected by concrete cross shafts. Large cages, first of iron and, later, concrete, have been used for molluscan culture. They measure $6 \times 4 \times 5$ m or 120 m^3. They function as fish attractors and concentrators (Fig. 4A). The French currently use two concrete modules, one polygonal spheroid 2.3 m high with a volume of 10.4 m^3, and the other a modular parallelepiped with a volume of 158 m^3. These units are hollow (Fig. 4C, D).

TARGET SPECIES AND FISHING. Depending on the objectives of the project, different modules are used with a different density of distribution on the ground, and, obviously, the target species vary. If antitrawling modules are scattered over a vast area, the target species are demersal species that have an annual spring–fall spawning migration, such as striped mullet (*Mullus barbatus*), some of the gurnards, soles, and cuttlefish. If the modules are used for attraction, concentration, and refuge, or designed for attachment of sessile organisms, or the gathering of benthic and nectobenthic species, the target species include, but are not limited to, the following: meagre (*Argyrosoma regius*), sea bass (*Dicentrarchus labrax*), sea breams, conger eels, several crustaceans (including lobster), and cephalopods. Certain species of bivalves are farmed, particularly, mussels and several species of oyster. These species are harvested with a variety of gear types. Fixed gears are used by small scale, local commercial fishermen to catch fish, crustaceans, or cephalopods. Gill and trammel nets, traps, and long-lines are also used. Bivalves are harvested by boats with specialized equipment (in surface floating systems), or by scuba-divers.

NUMBER AND SCOPE OF PROJECTS. The number of projects for artificial reefs in the Mediterranean is growing (Fig. 5). Gradually, fishermen are discovering the benefits of protected marine zones where it is possible to manage fishing. The pressure for new artificial reef development is increasing.

Italy. To date, 34 artificial reef projects have been planned for the coastal area around Italy. Of these, 7 have already been completed, 15 are in progress, and 12 are still on paper. The scope of these projects varies considerably, depending upon the supporting organizations. The projects range from those that cover some tens of hectares in a single zone, to thousands of hectares over many different zones. There are about 60 zones planned for the 34 projects as follows: 15 projects in the Adriatic, 9 in the Ligurian Sea, 5 in the Tyrrhenian Sea, and 6 in Sicily. The cubic measurement of the materials used varies from a few thousand cubic meters to several tens of thousands. The investment levels vary depending on the size of the project, its nature, design of material, and the cost of transport. Cost of projects range from hundreds of thousands to several million dollars. Sources of financing are provided by municipalities, provinces, and the state. In the latter case, the financing provided is matching funds to complete funds coming from the EEC. Within the EEC, construction of artificial reefs is facilitated by two EEC

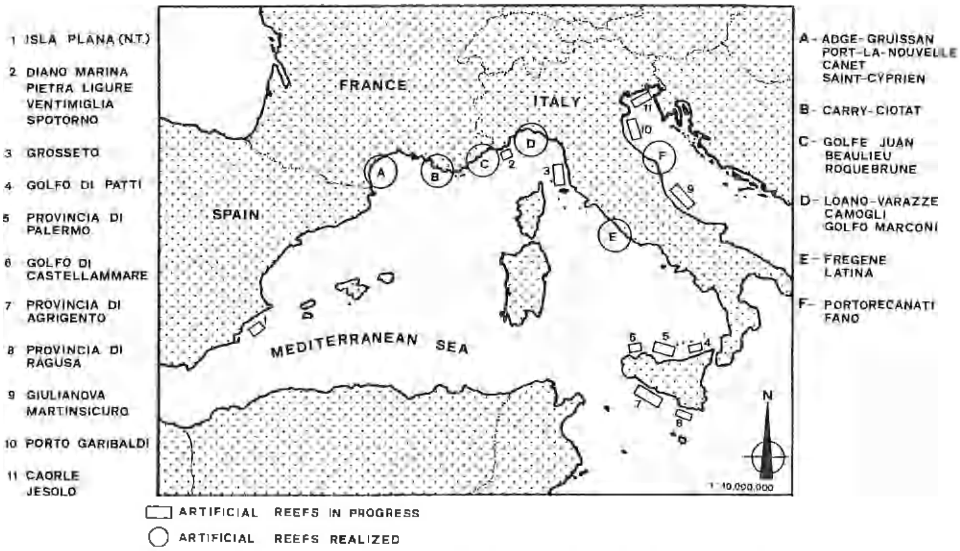

Figure 5. Location of artificial reefs in Western and Central Mediterranean Sea.

regulations, 2908-83 and 4028-86. The purpose of these is to improve economic and social conditions of the small-scale fishing industry and to increase employment through diversifying management of the coastal area.

France. In Mediterranean France, floating structures for mussel and oyster culture have been distributed along the Languedoc-Rousillon coast, specifically three near Sete, two near Cap Agde, one at Gruissan, one at Leucate, and one at Saint Cyprien. In this same span of coast, starting at Cap Agde going south, five artificial reef zones have been established. They are Agde (Hérault), Gruissan (Auge), Port-la-Nouvelle (Aude), Canet and Saint Cyprien (Pyrénéés Orientales). These are fixed bottom reefs, submerged at depths of 17 to 30 m (Fig. 5). The volume of material at Gruissan is calculated at 6,688 m^3 and it varies for the rest of the zones from 1,216 m^3 (Port-la-Nouvelle) to 2,420 m^3 (Saint Cyprien). Along another span of the coast, more to the north, artificial reefs have been installed around the area of Province-Maritime Alps-Côte d'Azur. Five protected marine zones also have been completed. They are: (1) *Regional Marine Park of the Côte d'Azur.* In the periphery of this park, artificial reefs have been created using solitary cubes of 150 m^3 totaling 1,700 m^3. (2) *Regional Marine Park of the Bay of La Ciotat* (nearing completion). (3) Protected and administered *marine zone of the Gulf of Juan.* This protected marine zone was created in 1980 for experimenting with artificial reefs for repopulating and protecting the marine environment. Since 1982, about 4,200 m^3 of different structures have been laid. (4) *Marine zone of Beaulieu-sur-Mer.* This zone was created in 1981. It covers 50 hectares off the Port of Beaulieu. It is a submerged reef, composed of 800 m^3 of alveolar and cubed shaped modules. (5) Protected and administered *marine zone of Roquebrune.* This marine zone was created in 1983. At present, 600 m^3 of cube shaped barriers have been submerged over 50 hectares.

Results

Here, we will address only the results we have had with artificial reefs of Porto Recanati (Middle Adriatic). These were planned, developed, and investigated by the Marine Fishery Research Institute (I.R.PE.M.) of the National Research Council (C.N.R.) of Ancona. Construction of this artificial reef began in 1974–1975. It consists of a nucleus of 12 pyramids (Fig. 3) each made up of 14 concrete blocks stacked in 9 + 4 + 1 pattern. Each block measures 2·2·2 m. The pyramids rest on a base of stones and are distributed along the perimeter of a rectangle of about 50 m from each other, over an area of 3 hectares, at a depth of 14 m. The blocks in the pyramid have a volume of 112 m^3 plus the base volume of the stones is 50 m^3. The complex of 12 pyramids for the 3 hectares totals 1,344 m^3, plus the stone base for the pyramids which measures 600 m^3. In 1978, fishing in this area intensified and, to protect the artificial reef area, 285 blocks were scattered irregularly throughout an area about 2,000 hectares around the 3-ha reef zone. The total volume of material used was about 4,300 m^3.

Fish Catches, Benefits, and Problems.—To evaluate the increase in resources and the cost/benefit ratio, the following were carried out: (a) Comparison of yields of fish caught with fixed equipment in the reef zone and in neighboring zones, (b) Evaluation and value of catches from the reef area, and (c) Comparison of the economic performance of small-scale fishing operations in and outside the reef zone. The results can be summed up as follows: (1) The average fish catches with trammel nets gradually increased at distances closer to the reef. (2) Catches in the artificial reef zones, depending on the species, are higher inside than outside as follows: (a) mussels, 1.4 times, (b) fish and cuttlefish, 2 times, and (c) gasteropods, up to 3.3 times. (3) The net proceeds for a fisherman operating within the reef zone is 2.5 times greater than those operating outside. (4) The cost of the reef zone, in eutrophic waters such as those of the middle Adriatic coasts, is recovered about 3 times in 7 years.

QUALITY OF THE CATCHES. Harvested fish can be differentiated as follows: (a) Fish native to the local bottom. The artificial reefs increase the size and fishable biomass of the fish by protecting the grounds from illegal trawling. (b) Fish attracted and concentrated by submerged structures in which they find refuge, and food. In this group we can differentiate: Pelagic (grey mullets, picarels, horse mackerels, others). Little is known about their trophic relationship with sessile and interstitial populations of the reef. Nectobenthic (sea breams, Dentex, sea bass, meagres, and some species of Labridae, and such like). These are precious fish of the reef and change the quality of the catch. Many of these have a direct trophic relationship with the small interstitial invertebrates (small crustaceans, and polychaetes) which nest in the byssus of mussels, in small holes, and in the gorges and rough areas of the artificial substrate. Benthics of the hard substratum (scorpion fish, conger eel). These settle in the cavities of the blocks. In addition to the fish, there are large crustaceans such as lobster (*Homarus gammarus*).

ATTITUDE OF FISHERMEN. At first, small-scale commercial fishermen were indifferent or doubtful. Only later, when they noticed increases in catches and the ability to defend their fishing gears from illegal trawling activities, did they become enthusiastic. Today, these same fishermen are asking for marine zones protected by artificial reefs. Trawl fishermen are gradually changing their attitude, also. At first, they were opposed, since the reefs prevented inshore fishing. But, they, too, have experienced increased availability of good sized, high value species near the reef. Today, some trawl fishermen are asking for marine zones protected by reefs (Ancona, middle Adriatic). Experience in the Adriatic has shown that the artificial reefs have encouraged cooperation among the small-scale commercial fishermen.

Problems Encountered.—Artificial reef technology is not without its own unique

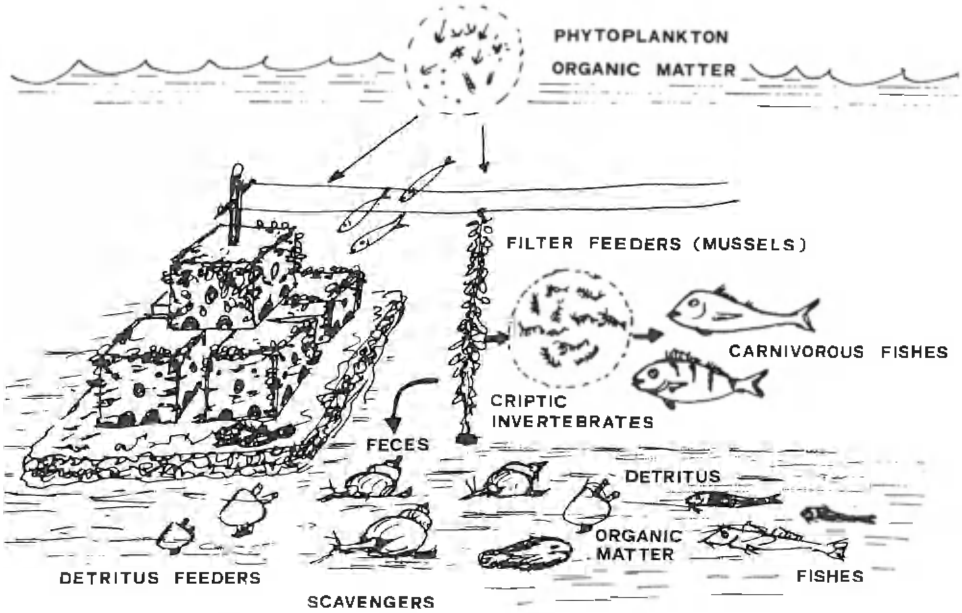

Figure 6. Diagram of food chain pathways for an artificial reef in Mediterranean eutrophic water.

series of problems. These can be identified as: (a) ecological and biological, (b) technological, (c) juridical, and (d) socioeconomical and administrative.

ECOLOGICAL AND BIOLOGICAL PROBLEMS. There is some argument over the ecological role of the artificial substrate. We maintain that reefs are not only a system for attracting and concentrating, but that they are also a mechanism for recycling energy from the environment, for priming new trophic chains in the area involved, and for increasing production (Fig. 6). It is also our opinion that the form and design of the structures plays a role in the attraction and concentration of the different faunistic components. But, a more detailed study must be made of the phenomenon of attraction and concentration and the shelter effect. The size and shape of the submerged materials is clearly important, but so is the deployment of the material, in height more than width, and the density of the individual modules compared to the area covered. Finally, the relationship between sedimentation and bioconstruction must be studied. Sessile bivalves risk being suffocated by siltation if the mollusks are not harvested annually. Finally, it is important to emphasize that the same reef using individual modules produces different biological effects depending on whether it is built in oligotrophic waters or eutrophic waters.

TECHNOLOGICAL PROBLEMS. Identification of all the technological problems would not be possible since not all have been identified. One of the more significant problems might be to optimize the yields from the installations of both fixed bottom and floating structures. Additionally, the designs chosen must be capable of withstanding the impact of weather, sea conditions, and the effect of trawling along the coast, among other factors.

JURIDICAL PROBLEMS. It is still difficult to obtain concessions granting the water space necessary for the installation of artificial reefs. The types of reefs must be classified. If the space involved is vast, and simple, small antitrawling reefs are planned, the problem of allocating space is avoided or reduced because the project benefits everyone. If, however, a multipurpose (repopulatioin, recycling, mariculture) reef is proposed, than concession of space may involve more restrictions to manage and administer the reef and its resources properly.

SOCIOECONOMIC AND ADMINISTRATIVE PROBLEMS. When a marine zone protected by artificial reefs has been completed, all fishermen, commercial, sport, skin divers, and others want to use the protected zone. The zone and its accompanying resources are not always sufficient to satisfy the total demand. Therefore, it becomes necessary to balance the number and range of the protected zones with the number and type of users. Administration and management involves controlling fishing operations, monitoring the catch levels, gear types and fishing periods, and, finally, close monitoring of the zone.

Outlook.—The future of marine zones protected by artificial reefs in the Mediterranean is uncertain. In Italy, commercial fishermen see benefits from these projects and are now promoting them. In France, there is still a wait and see attitude. Organizations and fishermen will be reviewing the current operations. The results may lead to increased interest and desire for more development. Spain is just beginning to consider the possibilities.

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