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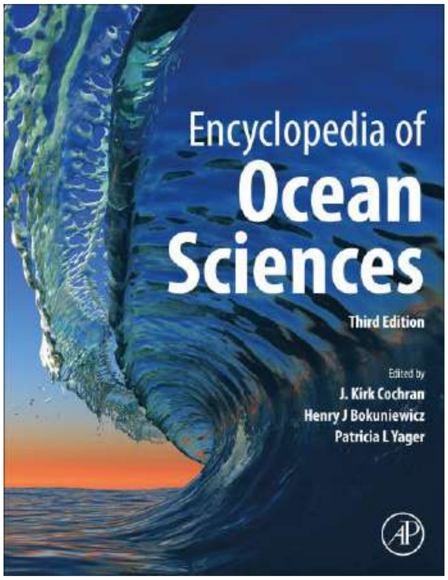

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ECOSYSTEMS & ECOSYSTEM STRUCTURE AND DYNAMICS (FOOD WEBS)

Contents

Artificial Reefs☆

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Introduction

Artificial reefs are benthic structures built of natural or human-made materials, deployed in thousands of locations worldwide for protection, enhancement or restoration of components of ocean ecosystems. Their ecological structure and function, degree to which they mimic natural habitats, and overall environmental and socioeconomic performance vary according to location, design, construction and conditions under which they are managed and utilized.

Over many centuries people have taken advantage of the behavior of some aquatic organisms to seek shelter at submerged objects by introducing structures into shallow waters, where biological assemblages could form and fishes could be harvested sustainably. Contemporary purposes for artificial reefs include increasing the efficiency of artisanal, commercial and recreational fisheries, producing new biomass in fisheries and aquaculture, expanding underwater recreation and ecotourism opportunities, preserving and renewing coastal habitats and biodiversity, and advancing research and education.

This article reviews the evolution, distribution and increased scale of artificial reef habitat deployment practices globally, reports growing scientific understanding of them, and describes trends concerning their planning, evaluation and appropriate application in resource management. While the focus of this article is on deliberately submerged structures intended to influence physical, biological or socioeconomic processes, it is noteworthy that de facto habitats may result from coastal engineering works, sunken ships or energy production platforms.

☆*Change History:* April 2018. W. Seaman revised/updated Abstract and Introduction to reflect updated text. Additional coverage of research findings was provided throughout, reflecting the growing global effort to document artificial reef ecological structure and function. The section on reef purposes and placement was updated with recent quantitative measures of impact. The section on scientific advances was broadened to refer to biological, engineering and economic studies. Planning was expanded with more information about steps in reef planning and measurement of performance. Additional information about artificial reefs in ecosystem management was given. A new list of references was made. Two new figures (# 7, # 9) were added. (The other eight figures are carried over.)

This is an update of W. Seaman, W.J. Lindberg, Artificial Reefs, *Encyclopedia of Ocean Sciences* (2nd Edn), edited by John H. Steele, Academic Press, 2009, pp. 226–233.

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Purposes and Placement of Artificial Reefs in the World's Oceans

The near-shore ocean ecosystems of all inhabited continents contain thousands of artificial reefs.

The origins of artificial reef technology are traced to places as diverse as Japan and Greece. The earliest reef structures were made from natural, locally sourced materials, to support artisanal and subsistence fishing in coastal communities, particularly in tropical areas (Fig. 1). In India, for example, traditionally tree branches have been weighted and sunken. Brush parks made of branches stuck into the substrate have been used in estuaries of Sri Lanka, Mexico and several African countries. In the Caribbean basin, *casitas* of wood logs provide benthic shelters from which spiny lobsters (*Panulirus argus*) are harvested. Indigenous knowledge of local fisherfolk is important in sustainably managing these reef systems.

In recent decades, some artisanal fishing communities have deployed new designs of artificial reefs, and at larger scales. In part, this has been in response to damage of habitat and fisheries by coastal land-use practices and competing, more intense fishing practices such as trawling. A national effort in India has deployed reef modules of steel plates, to increase the time fishing cooperatives actually devote to harvest as a means of promoting social and economic well-being. As part of a plan to balance small- and large-scale fisheries in the coastal waters of Thailand between 2400 and 3300 concrete modules were located in areas of 14–22 km^2.

Modern deployment of reefs (post-World War II) has the longest history and has been most active in Eastern Asia, Australia, Southern Europe, and North America. The technology has spread to scores of nations worldwide in Central and South America, the Indo-Pacific basin, Northern Europe and parts of Africa. No organization maintains a database for artificial reef development globally, so that proxies must be derived from the records of regional or national economic development, fishery and environment organizations, as well as from scientific journal and other reports.

The most extensive deployment of artificial reefs, for any purpose, is in Japan. There, fishing enhancement has been the goal of a national plan begun in 1952 and since greatly expanded. Japanese objectives have been to develop nursery and reproduction sites and thus create fishing grounds to supply seafood including abalone, clams, sea urchins, crustaceans and finfishes. This came about partially in response to the closure of distant waters to fishing by other nations. By 2004, 12% of the continental shelf ($<$ 200 m depth) of Japan had been affected by reef development. Industrial manufacturers have used materials such as steel, fiberglass, and concrete in structures that are among the largest units in the world, attaining heights of 35 m, widths/diameters of 27 m, and volumes of 3600 m^3 (Fig. 2).

Fig. 1 In some areas of long-standing artisanal fisheries, structures such as the *pesquero* (left), a bundle of mangrove tree branches, are used for benthic structure, as in Cuba. More recently, small fabricated modules, such as this example from India (right), are used to complement or replace natural materials.

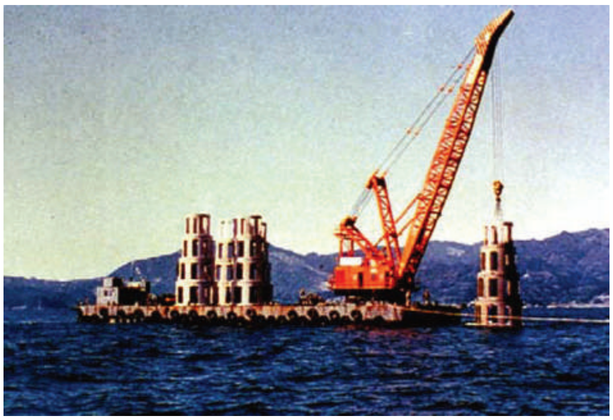

Fig. 2 The largest reef modules have been fabricated and deployed in Japan.

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Other regions more recently deploying artificial reefs to enhance or simply maintain artisanal and commercial fisheries to supply human foodstuffs include southern Europe and Southeast Asia. Among 19 European nations having over 250 total artificial reefs, those along the Mediterranean Sea and Iberian Atlantic coasts focus on fisheries and ecosystem management goals of protecting sensitive habitats against illegal trawling, enhancing small-scale fisheries and reducing conflict among stakeholders. Their usual approach has been to design, experimentally test, and document reef performance. As early as the 1970s, 8 m^3, 13 ton concrete blocks were deployed in the Adriatic Sea of Italy (with a total of 70 reefs along all coasts), forming reefs of volumes up to 13,000 m^3 and coverage up to 2.4 ha. Objectives have included: Shelter for juvenile and adult organisms; reproduction sites; capture of nutrients in shellfish biomass; protect fish spawning and nursery areas from illegal trawling; and protect artisanal set fishing gear from illegal trawling damage. Higher catches and profits for small-scale fisheries have been recorded.

In Spain (103 reefs total) heavy concrete and steel rod reef designs have been used effectively to protect seagrass beds from illegal trawling (Fig. 3). In Portugal fishing yields from artificial reef sites have consistently exceeded those from control sites, with economic analysis showing that earnings from them were about 13 euros more per unit of effort than at control sites (2008 values).

In contrast to emphasis on seafood production, enhancement of recreational fishing was the initial goal of artificial reef deployment in Australia and to lesser degrees in the northern Mediterranean Sea, Northern Ireland and Brazil. The United States was the earliest entrant in this field, shortly after the end of World War II. This nation has built thousands of artificial reefs through numerous, independent and mostly small-scale efforts organized by local interest groups or governmental organizations at the individual state level. Historically, so-called "materials of opportunity" predominated, including discarded solid waste such as automobile tires and bodies, home appliances and railroad cars, now largely discontinued. Heavier and more durable "secondary use" materials such as concrete rubble from bridge and building demolition sites and derelict vessels continue to be used, but according to more formal placement schemes. Designed, fabricated structures are becoming more common (Fig. 4). One state, Florida, has about half of the nation's total number of reefs, and in one 4-county area annual expenditures by nonresidents and visitors on fishing and diving at dozens of artificial reefs were US $1.7 billion (2001 values).

Fig. 3 Concrete reef modules with projecting steel beams such as railroad tracks are deployed in protected marine areas of Spain to discourage illegal trawling, so as to promote restoration of seagrass habitats and fish populations. Photograph Courtesy of Juan Goutayer.

Fig. 4 Artificial reefs of concrete are used worldwide, with designs increasingly intended to meet ecological requirements of designated species and habitats.

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Artificial reefs also are used as part of a larger strategy to implement marine ranching programs. In Korea, for example, the decline of distant water fisheries led to a transition from capture-based to culture-based fisheries. From 1971 to 1999, artificial reef placements have affected 143,000 ha of submerged coastal areas, out of the total 307,000 ha planned. At certain long-term experimental reef sites, hatchery-reared juvenile invertebrates and fishes have been released, with enhanced fishery yield reported. Artificial reefs are used elsewhere exclusively for aquaculture, for example, in settings where excess nutrients stimulate primary production that is transferred into biomass of harvestable invertebrate species, such as mussels (*Mytilus galloprovincialis*) and oysters (*Ostrea edulis* and *Crassostrea gigas*) in Italy. Annual mean biomass of commercial mussels settled on reefs in the western Adriatic Sea has been measured at 17 to 55 kg m^{-3}.

Restoration of marine ecosystems using artificial reefs has focused on plant and coral communities. Along the coast of the Northwest Mediterranean Sea, artificial reefs are deployed in protected areas to preserve and promote colonization of seagrasses (*Posidonia*). On the Pacific coast of the United States mitigation for electric power plant environmental impacts required a 61 ha artificial reef for kelp (*Macrocystis pyrifera*) colonization, survival and growth. In numerous tropical areas, artificial reefs have been used in repairs to damaged coral reefs (Fig. 5), or to hasten replacement of dead or removed coral. In the Philippines, for example, hollow concrete cubes are deployed as sites for coral colonization, sometimes being located in marine reserves. In the Baltic and Black Seas artificial reefs are installed with the aim of reducing eutrophication from fish farming and other human activities.

Increasing popularity of artificial reefs to promote tourism is seen in the development of diving opportunities, both for people in submersible vehicles and for those who scuba dive, snorkel and spearfish. In places such as Mexico, the Bahamas, Monaco and Hawaii submarine operators provide trips to artificial reefs, some featuring works of art. On a larger scale, obsolete ships have been sunk to create recreational dive destinations in areas as diverse as British Columbia (Canada), Oman, New Zealand, Mauritius, Israel and the United States. Impacts include generation of economic revenues in local communities and diversion of diver pressure from natural reefs. Advantages of having artificial reefs dedicated to recreation and marine ecotourism include their nonconsumptive aspect and suitability for nature-based education.

Not all structures placed on the sea floor have been put there purposefully and with the primary intent of creating benthic habitat or managing in some other way the marine ecosystem. Of significance numerically and ecologically are both intentional works of engineering, such as rock jetties for shore and harbor protection, offshore steel platforms and towers used in exploration and production of fossil fuels and wind power, and also accidentally sunken vessels. Regardless of origin they serve as de facto reefs, with functional biological equivalency between rock breakwaters and natural outcrops having been shown, for example, in a 25-year study in California, United States. Meanwhile, a 1999 survey in the northern Gulf of Mexico estimated over U.S. $800 million in trip- and equipment-related expenditures by recreational fishing and diving enthusiasts visiting so-called "rigs."

Progress Toward Scientific Documentation of Artificial Reefs

Research on artificial reefs is conducted worldwide, in a growing number of disciplines, and reported in an increasingly diverse array of technical publications. It is closing a gap between the science and the applications of this technology, while contributing to fundamental knowledge of ocean systems. Investigations have broadened from an early emphasis on descriptive biological studies. Increased scope and rigor has in some cases been enabled by methodological advances such as improved underwater biological census techniques to determine species abundance and recruitment, the application of more powerful remote sensing techniques to

Fig. 5 This larval enclosure tent is for settlement of the coral, *Montastraea faveolata*, at the site of a ship grounding on Molasses Reef, Florida Keys National Marine Sanctuary, United States. Coral are mass-spawned, larvae cultured through the planktonic phase, and then introduced into the tent. In the laboratory, larvae may settle onto rubble pieces which subsequently are cemented to the reef. Photograph by D. Paul Brown.

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assess stability of reef materials, and economic and biological modeling. Comparative studies of natural and artificial habitats have advanced understanding of both systems.

In particular the earlier history of research on artificial reefs may be characterized by the subjects, methods and findings reported at 11 international conferences held from 1974 to 2017. Relatively large numbers of peer-reviewed articles contained in three pre-2000 proceedings peaked with the 1991 conference (84). Subsequent decreases in number of gathered conference papers does not however reflect declining research activity, for two reasons: Scientists increasingly are reporting via their respective disciplinary networks and reviewed specialty journals devoted to fish biology, fisheries, marine ecology, coastal engineering, economics, recreation/ecotourism, human behavior, resource allocation and ocean policy, among other subjects. Also, quadrennial reef conference venues since 2009 (Brazil, Turkey, Malaysia) have been less accessible to the relatively larger number of researchers in North America and western Europe, and the global economic downturn during that time likely impacted funding for travel.

Colonization of artificial reefs has the oldest and most extensive record of scientific inquiry. Appearance of larger (adult) fishes at some reef sites almost immediately after placement of structure is the most visible form of occupation. This phenomenon is cited as a factor in the so-called "attraction-production" debate. However, microbes, plants, invertebrates and immature and smaller adult fishes also colonize reefs (Fig. 6). Fig. 7 depicts a much-discussed and increasingly studied conceptual framework for how fishes associate with artificial reef structure, along a continuum, ranging from visits that provide limited biological benefit to some species such as large transient fishes to partial or permanent residence with feeding and reproduction particularly by smaller fishes. Early experimental comparison of patch reefs of stacked concrete blocks with translocated coral reefs in the Bahamas (Fig. 8) determined that the reefs had similar fish species composition, while the natural reefs supported more individuals and species, owing to their greater structural complexity (i.e., variety of hole sizes) and associated forage base. Newer research includes more ecological process-oriented study of sheltering, recruitment, reproduction, feeding, growth and production of biomass.

One indicator of production of biomass at artificial reefs is recruitment and growth of organisms. Long-term studies of spiny lobster experimentally established that artificial reef structures, with dark recessed crevices approximately one body-length deep and multiple entrances, augmented recruitment in a situation of habitat limitation in the Florida Keys, United States. Application of stable isotope analysis to reef organisms in Marseille, France determined that dissolved organic matter was converted to biomass by sessile filter-feeding invertebrates attached to artificial reefs and also demonstrated reef-based secondary production, especially in piscivorous fishes.

Ocean engineering practices are applied worldwide for construction of stable artificial reefs, as reflected throughout this article. A significant body of early work in Japan enabled the deployment of towering offshore frameworks. More recently experiments focused on oceanic hydrodynamic processes by building seamounts at depths up to 150 m to deflect bottom currents and bring nutrients to upper waters. Modeling of reef dimensions and spacing is a newer endeavor.

Economists more recently have addressed questions about usage of artificial reefs, economic activities associated with them, and cost-benefit. Accordingly, methodologies of increasing complexity have been refined for (1) monitoring, (2) impact assessment and (3) efficiency analysis as a means of informing ocean policy issues such as fishery yield, revenue and allocation. Such studies in the Algarve of Portugal, for example, led to a scaling up of reef deployment from pilot efforts to establish a system of "protection" and "exploitation" reefs in an area of 4 km^2, containing over 21,500 modules, one of the largest in Europe.

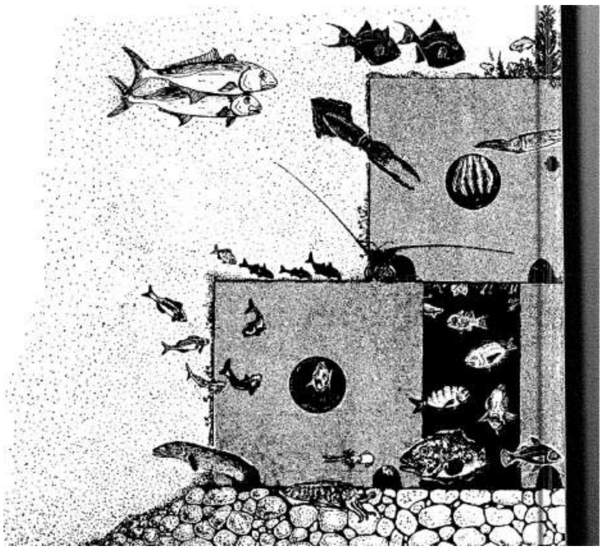

Fig. 6 Aspects of attachment surfaces for marine plants and shelter and feeding sites for invertebrates and fishes provided by artificial reefs. Drawing courtesy of S. Riggio.

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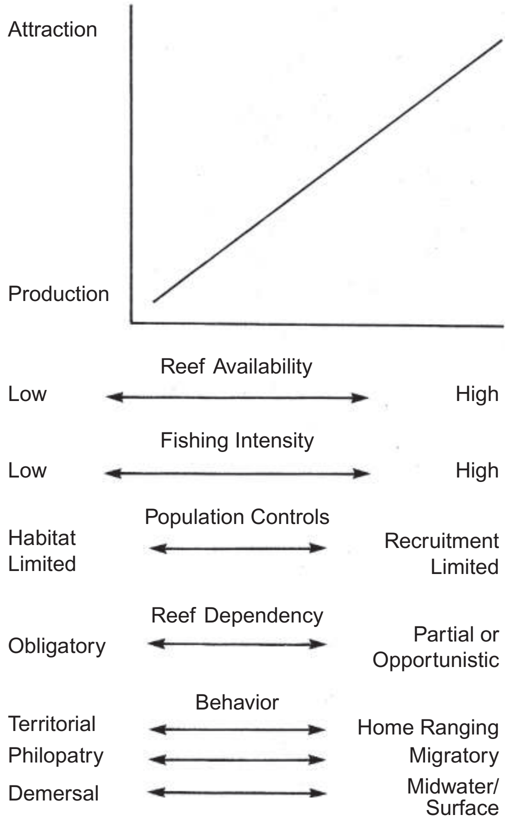

Fig. 7 Gradients predicted to be important for attraction or production of fishes at artificial reefs. Linear responses are shown for illustration purposes. From Bohnsack, J. A. (1989). Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? *Bulletin of Marine Science* **44**, 631–645.

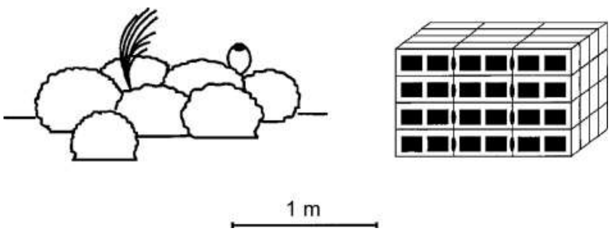

Fig. 8 Experimental modules such as the one pictured on the right from the Bahamas exemplify a global trend toward greater manipulation of artificial reefs as tools for testing of hypotheses concerning ecological processes in the ocean, and comparison with systems such as coral reefs, pictured left. Drawing courtesy of American Fisheries Society.

Planning, Design and Construction Advances to Improve Artificial Reef Performance

The growing number, cost, size, intricacy, footprint and purposes of structures deployed on what is still just an extremely small portion of the world's sea floor has prompted greater emphasis on their planning. Its aims are to (1) promote more efficient and cost-effective structures, (2) enable work at larger physical and geographical scales and with more precision, (3) satisfy legal and regulatory requirements, (4) reduce conflicts with other natural and human aspects of ecosystems, (5) minimize the prospects of unintended consequences from improperly constructed reefs, (6) define accountability criteria for measuring outcomes, and (7) achieve overall resource management objectives. Evolving explanations of physical, hydrodynamic and biological behavior of reefs are leading to designs more consistent with abiotic and biotic factors of the natural environment and thus life history requirements of marine species. The ecological and economic impacts of poorly designed artificial reefs, meanwhile, are exemplified by an effort in the United States—projected to cost US $5,000,000 (2015 figures)—to remove 2,000,000 automobile tires that were deployed over 14 ha in the 1970s, but which are drifting off-site with damage to adjacent live coral reefs and beaches.

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Independently in different geographic areas, common approaches and a small number of formal published guidelines for developing artificial reefs have emerged. The earliest handbooks originated in Japan, focused on physical and oceanographic conditions as first addressed by the national Coastal Fishing Ground Enhancement and Development Project. (Translations of certain documents into English in the 1980s by the United States National Marine Fisheries Service disseminated some of this information.) The United States revised its two decades-old national plan in 2007 under directives of the National Fishing Enhancement Act. In turn it is used as a resource by numerous coastal states where much of the nation's intentionally decentralized efforts in reef planning and deployment are independently administered. Other countries where planning is done through a coordinated reef program run by a federal or provincial marine or fishery resources organization include Italy and China.

For other places such as the Aegean Sea of Turkey and northern Taiwan, where reef deployment is limited to selected localities or areas, but is not nationwide, master plans or other guidelines also have been produced. Unique at a multinational level are European guidelines addressing the entire Mediterranean and Black Sea region. Notably this document lists 12 possible negative impacts of artificial reefs, both environmentally (e.g., increase of contaminants in water and sediment, displacement of natural sensitive habitats, invasive species) and socioeconomically (e.g., conflict among users), and gives guidance on their avoidance or mitigation.

The assortment of artificial reef planning documents have in common a set of procedures, considerations and best practices that generally reflect a stepwise progression of effort, with engagement of relevant stakeholders, including, with appropriate feasibility and pilot studies, (1) initial formulation of a concept and overall goal for the reef, (2) evaluation of specific reef sites and the ecosystem in which the development is proposed, and how the reef will affect it, (3) determination of how the reef fits into the locality's resource management framework, (4) establishment of specific and measurable objectives, (5) development of possible designs and siting placement for reef structures, (6) designation of materials and construction practices, (7) compliance with appropriate regulatory, liability, maintenance and related requirements, (8) stipulation of a statistically rigorous, comprehensive monitoring and assessment program to evaluate performance, including database management, and (9) communications to lay and technical audiences. Effective planning ordinarily involves a multidisciplinary approach using expertise of biologists, engineers, economists, planners, sociologists, and others, engaged with other stakeholders.

From a physical standpoint, key aspects of design and the construction phases of fabrication, transportation and placement include geological stability of a seafloor site, durability of the reef configuration, and potential adverse impacts in the environment. To build a quantitative understanding of the environment into which a reef is to be placed, large-scale oceanographic processes and local conditions must be determined by site surveys early in reef planning, including water circulation driven by tides, wind and baroclinic/density fields, locally generated wind waves, swells propagated from distance, sediment/substrate composition, distribution and transport, and depth. These factors are then coupled with attributes of the reef material, such as weight, density, dimensions and strength, in order to forecast reef physical performance.

From an ecological standpoint, abiotic and biotic influences considered in design include geographic location, type and quality of substrate surrounding the reef site, isolation, depth, currents, seasonality, temperature regime, salinity, turbidity, nutrients and productivity. Attributes of the actual structure that affect ecology of the reef include its composition, surface texture, shape, height, profile, surface area, volume and hole size, which taken together contribute to the structural complexity of the reef. Spacing of individual and groups of reef structure is important.

Repeatedly, authorities cite complexity of structure as a primary factor in successful design. Another of Europe's largest reefs (27,300 m^3), in southern France and intended to restore artisanal fishing, took 3 years of planning. It uses six types of fabricated modules of different shapes, sizes, volumes and materials, made yet more complex by addition to interior spaces of objects such as bags of oyster shells, concrete blocks, octopus pots and floating ropes. The guiding design principle was to create horizontal and vertical discontinuities in heights, sizes, and volumes using a variety of reef types and shapes with diverse arrangement and horizontal spacing of reef structures. Boulders of varied sizes also were deployed, to reconstitute natural rocky habitat for target species such as grouper and sea bream. Meanwhile, at a much smaller scale in Monaco testing of innovations in computer-driven design and construction of reef material is underway (Fig. 9).

Design practices for artificial reefs have changed dramatically due to growing emphasis on using natural and manmade materials that conform and contribute to the life history requirements of organisms including those desired as part of the reef assemblage. In a situation concerning fishing, one of the designs used in Korea is the box reef, a $3 \times 3 \times 3$ m concrete cube (Fig. 10), targeted to two species: small, dark spaces in the lower two-thirds of the reef are provided for rockfish (*Sebastes schlegeli*), while the upper third is more open to satisfy behavioral preferences of porgy (*Pagrus major*). Subsequent monitoring determined production of fish biomass and increased fishery revenues. Similar results have been reported at reefs in Portugal, for example, where experiments quantified production of sessile invertebrates and feeding there by fishes including sea bream, *Diplodus*.

Greater specificity for reef objectives has been accompanied by demands for more rigorous measurement of the performance of reefs in meeting those objectives. Thus, for a mitigation reef aiming to create new kelp beds (*Macrocystis pyrifera*) off California, United States, biologists and engineers concluded that the most effective design should place boulders and concrete rubble in low-relief piles (< 1 m height), at depths of 12–14.5 m, on a sand layer of 30–50 cm overlaying hard substrate. Quantitative success criteria included attainment of support of four adult plants per 100 m^2 and invertebrate and fish populations similar to natural reefs. Pilot studies found similar fish species diversity and abundance at reef and control sites.

As larger artificial reefs are planned, more entities are first using pilot projects to determine physical, biological, economic and even political feasibility. The 42,000 ton Loch Linne Artificial Reef in Scotland was started in 2001 as a platform for scientific investigation of the performance of different structures, ultimately to establish fisheries for target species, specifically lobster

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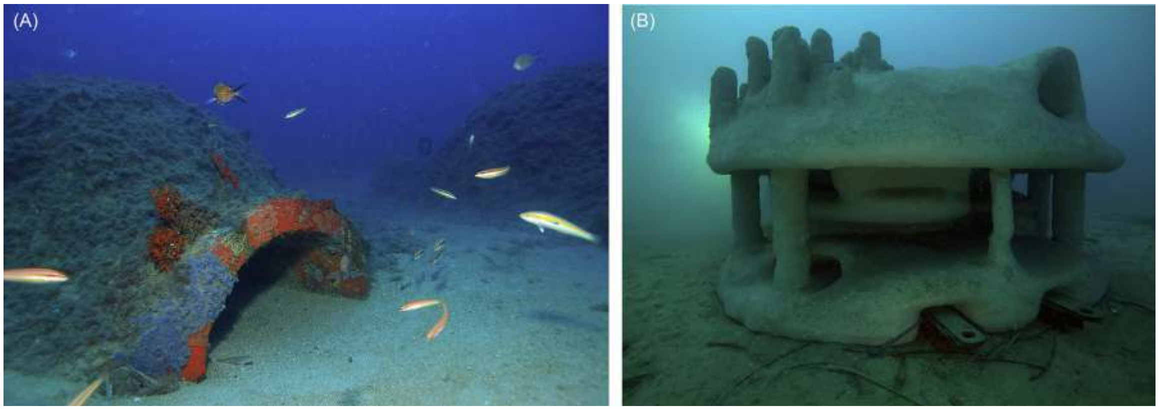

Fig. 9 (A) Dome-like structures of concrete, approximately 3.3 m diameter and 1 m high and known as "Thalamé reef units," were deployed beginning in 1989 in coastal waters of the Principality of Monaco to provide shaded habitat conducive to restoration of red coral, Corallium rubrum. (B) In 2017, 3D printing technology was used to produce physically complex reef structures of dolomite sand, approximately 2.2 m diameter and 1 m high, for experimental deployment in restoration of inshore marine reserve biodiversity in Monaco. Courtesy of P Francour.

Fig. 10 The box reef design used in Korea resulted from a collaboration of engineers and biologists. Modules have been placed in research plots within Tongyong Marine Reserve for use in experiments with stocking juvenile fishes. Photograph by Kim Chang-gil.

(*Homarus gammarus*). This effort reflects a trend toward increased predeployment research. In this case a 4-year study of seabed, water column and biology.

Coupled with preference for science-based design of structures is the artificial reef development community's move away from use of many objects intended for another primary purpose or simply seen as solid waste for disposal cheaply. Notable exceptions still used widely include high density, durable, heavy materials including concrete demolition rubble from bridges and roadways, obsolete or derelict vessels, and heavy-gauge metal platforms used in offshore energy development. For all secondary materials there is a need to handle, prepare and place them in environmentally compatible ways. In Canada, for example, decommissioned naval vessels require extensive removal of electrical wiring and other components to eliminate release of pollutants into the sea, in conformance with strict federal rules, before deployment as recreational scuba diving sites.

In the eastern Pacific Ocean, North Sea, Adriatic Sea and northern Gulf of Mexico offshore oil and gas production platforms provide a considerable area of hard surface for sessile organism attachment and thus act as de facto reefs. They may be modified in place or transported to new locations to serve as dedicated reefs, which costs less than removal to land. The US waters of the Gulf of Mexico contain over 4000 platforms, of which over 400 have been "reefed," that is, repurposed as permitted artificial reefs. Analysis of monitoring by remotely operated vehicle cameras and supplemental longline fishing gear in Texas has developed descriptions of fish community structure at sunken ships and different configurations of rig components, from which conclusions and recommendations about optimum placement of structure were made: for example, location of rigs (<30 m height) at 50 m depth favors both "offshore" and "bluewater" groups of fishes and can "improve the abundance" of red snapper (*Lutjanus campechanus*) to fisheries.

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Ongoing Integration of Artificial Reefs in Ocean Science and Resource Management

Continuing research advances and practical experiences in design, deployment and utilization of artificial reef habitats in the sea have created a body of knowledge that is building confidence in the technology among stakeholders. One indicator is the extent to which private consultants and businesses have found growing markets for their services and products, with just one patented design (among many) being used in about 60 countries. Also emerging is the planning and evaluation of artificial reef projects in an adaptive management framework, in which expectations are more explicitly stated, projects more rigorously evaluated, and then adjustments made to management practices. Part of moving the application of artificial reef technologies toward higher standards of sustainability and practical effectiveness is due to the attention—with healthy skepticism—by international scientific and management bodies such as the North Pacific Marine Sciences Organization and the Food and Agriculture Organization, which are addressing the relevance of artificial reefs to core fisheries issues such as stock enhancement, fishing regulations and conservation. Further, integrated coastal management in the Philippines, India, Spain, and elsewhere now includes artificial reefs in multifaceted responses to issues of habitat destruction, fishery decline, and socioeconomic development. In some cases artificial reefs are deployed in marine reserves as a tool in conserving or restoring biodiversity. With increasing multidisciplinary and long-term databases there are greater possibilities for use of ecological simulations to analyze scenarios of reef development and how manipulation of habitat affects the ocean.

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