Does the level of design influence success of an artificial reef?

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Abstract

Design addresses the composition, arrangement and location of materials used as or in artificial reefs. Design practices range from the traditional use of natural materials by generations of artisanal fishermen to more recent fabrication of large and specialized structures in commercial fishing and habitat restoration. The largest concentrations of reefs exist in older programmes in Japan and the United States, and newer efforts in Europe and Southeast Asia.

Factors incorporated into the design of reefs come from three broad disciplinary areas: (1) Economics, with considerations of usage patterns, costs and benefits, is least studied; (2) Engineering/physical sciences, with some well developed principles for stability, longevity and deployment of materials, is most definitive; and (3) Biology, with a broad yet often incomplete literature concerned with numerous issues such as reef size, profile, texture and several other biotic factors. Quantitative evaluation of the performance of reefs has not kept pace with the application of the technologies. Research focused on the specific objectives for which a reef is created will further both science and management in this young field.

Keywords: Artificial reefs; Materials; Construction; Design; Evaluation

(1) Introduction

The history of thousands of artificial reef placements in coastal and ocean waters worldwide includes some failures, and therefore basic elements of design clearly are required for planning any reef development. Also, it can be argued that quantitative evaluation of reef performance has not kept pace with expanding applications of these technologies. Within this general context we need to explore whether some minimal amount of information is required or available to design a habitat that will satisfactorily meet its objectives. Further, can additional gains in productivity be achieved as design becomes more sophisticated?

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Design is only one step in the process of artificial reef development (Figure 1). Once the need for an artificial reef is determined and a purpose and objective are defined, a design element would be conducted in order to determine location, materials and other aspects of the reef structure. Subsequently, deployment, actual use, and hopefully evaluation would occur, the latter element to feed back information for future planning and design. Much of the literature about reef planning is in individual articles in journals or technical reports, while "reef plans" have been written on a limited basis at national (e.g., Japan) or regional (e.g., some states in the United States) levels.

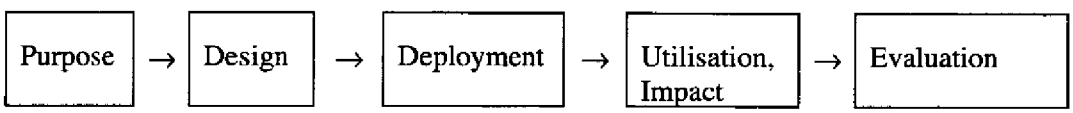


Figure 1: Relationship of design and other elements of artificial reef planning

(2.1) Overview of reef designs

In this section I focus on the aspect of design related to the overall physical appearance of artificial reefs. The designs of the reefs depicted in Figure 2 obviously vary in level of technical data required for their establishment. Artisanal structures of brush or wood, for example, are relatively simple in design and construction (e.g., logs bound together as a cover resting just above the seafloor, as shelter for spiny lobster in the Caribbean Sea, Figure 2B). Expensive and larger structures fabricated of steel, fiberglass and concrete formed into precise geometrical configurations that are deployed using heavy equipment require more complicated mathematical and engineering procedures (e.g., as seen in Japanese commercial fishing, Figure 2E, F). In the former situation, the knowledge base is more anecdotal and draws on the historical observations and culture of the peoples; in the latter a quantitative database has been created using laboratory and experimental procedures. A question posed to this conference is, "Does greater (so-called) 'sophistication' of design result in proportionately greater benefits to users of the reef?"

The most recent synopsis of the scope and extent of global artificial reef development (Stone *et al.*, 1991) focused on geographic extent, objectives and programmatic aspects. While these authors identified some of the materials and structures used,

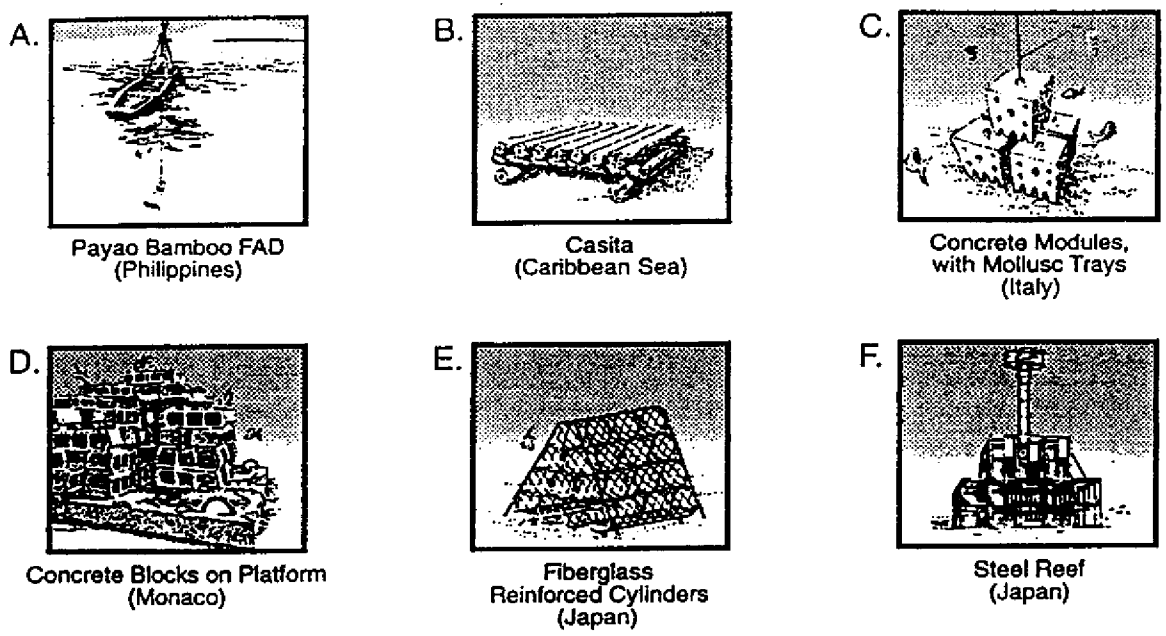


Figure 2. Representative artificial reef structures reflecting varying levels of complexity in arrangement of components.

Table 1. Design of artificial reefs is defined by three aspects.

	Aspect		
	Composition	Arrangement	Location
Definition	Materials used	Assembly of materials	Footprint = pattern + area; Geographic site
Level of Control			
- Low	Opportunistic (e.g., surplus items)	Random Arrangement (e.g., pieces of rubble)	Accident-prone (e.g., crush coral)
- High	Selective (e.g., molded fiber-glass)	Detailed fabrication (e.g., modules)	Precise Siting (e.g., adjacent to natural reefs)

Newer reef construction efforts globally are attempting also to account for composition and construction aspects of reef design, emulating the traditional Japanese approach. Thus, along the northern coast of the Mediterranean Sea basin, for example, a variety of structures designed specifically as artificial reefs have been constructed. Figure 3 offers representative "designed" benthic habitats. Structures in Japan may be built at a larger physical scale (Figure 3A), whereas reefs in the Mediterranean are generally smaller (Figure 3B).

In recent years a new category of reefs has been built exclusively for research. These structures are carefully designed, constructed and deployed. Typically they are small and assembled from modules, such as one cubic meter concrete blocks. (Contrasts between so-called "Study Reefs" and larger more ubiquitous "Application Reefs" are in a companion paper prepared for this conference (Seaman, this volume).

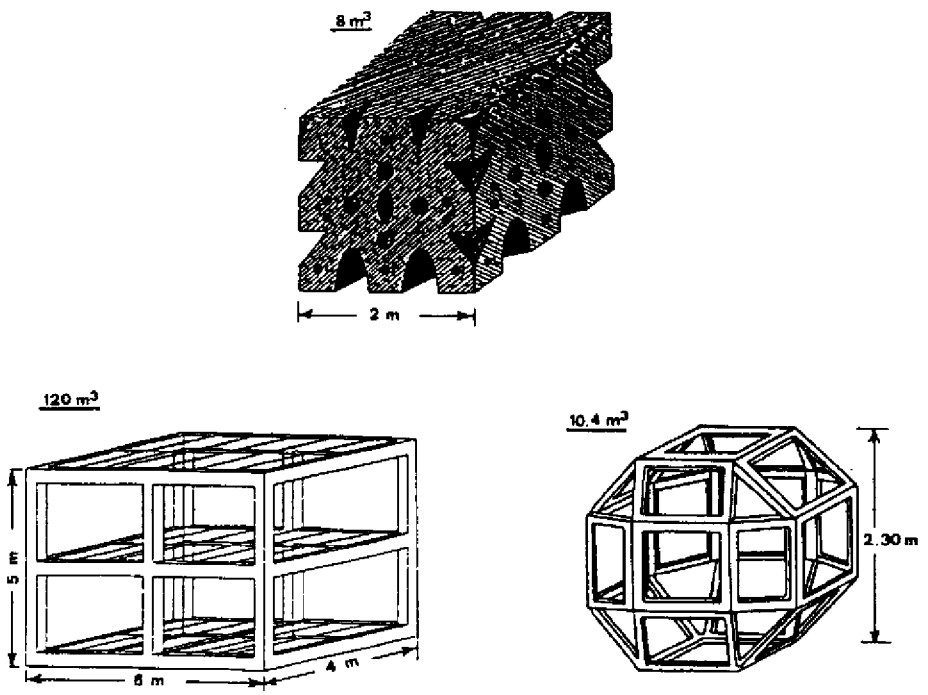
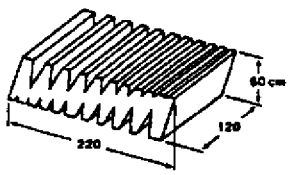


Figure 3: Examples of artificial reefs fabricated according to highly controlled aspects of composition and construction. (facing page, structures from Japan; this page, Mediterranean Sea.)

Table 2. Incorporation of scientific principles in design of representative artificial reef structures according to purposes of marine interests.

Interest sector and purpose	Example of reef structure	Scientific principle(s) embodied in design
Artisanal Fishing: Harvest, Subsistence	Brushpark (wood)	Behavioral attraction, habitat for epifauna
Commercial Fishing: Harvest, Income	Abalone Block (concrete)	Shelter, optimize metabolism and growth
Recreational Fishing: Harvest or Catch-and-Release, Leisure	Roadway Rubble (concrete)	Habitat limitation, angler accessibility
Habitat Access and Use: Restoration, Refuge	Barrier Block (concrete)	Prevent physical disturbance
Eco-tourism: Recreation, Income	Battleship (steel)	Visual diversity
Environmental Mitigation: Replace Habitat	Kelp Bed (concrete)	Habitat limitation, food webs, refuge

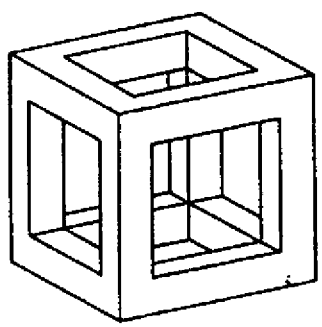
A review by Grove *et al.* (1991), of the merger of an understanding of fish behaviour and a knowledge of physical ocean processes in Japanese efforts to fabricate reef structures (rather than deploy rock or other materials), summarizes some major developments in this field. These authors include findings which previously were only printed in Japanese. They draw from literature of the Japan Coastal Fisheries Promotion Association, which includes the 1979 and 1984 versions of a design manual entitled "Coastal Fisheries Development Program: Structural Design Guide." Among the factors which are addressed by various mathematical formulas for benthic reef structures are:

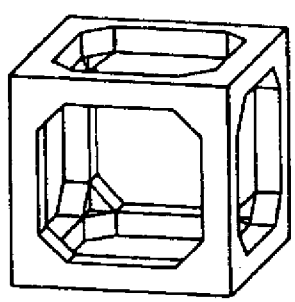


Abalone Nursery Block

(A) Cube

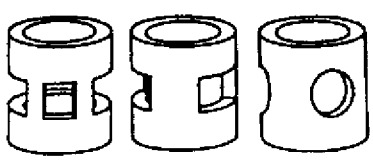
(B) Cube





(C) Cylinders

(D) Large Cylinder



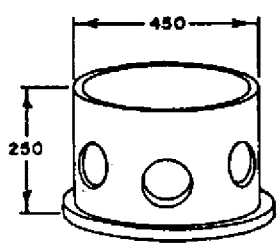


Figure 4: Modular structures, usually of concrete, are in greater use in the world's artificial reefs.

of habitat complexity:

- material composition
- surface texture
- shape
- height
- profile
- hole size
- size (of reef)
- scale (temporal, spatial)
- dispersion (of reef materials)

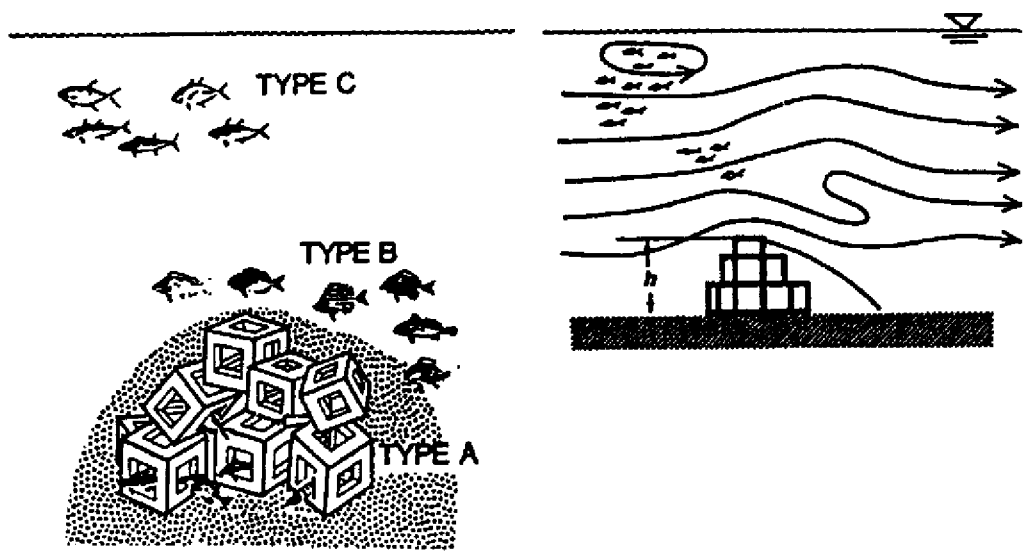


Figure 5: Japanese research has characterized the affinity of some fishes to artificial reefs as (A) benthic dwellers in physical contact with it, (B) linked to it visually only, and (C) at some distance to it. The latter group might be in a "lee wave." (Redrawn from Grove *et al.*, 1991)

(3.3.2) Individual design factors

This section offers highlights of selected research that is more intensive, longer, and focused on specific factors on which design is based. Included are some of the most extensive databases in the western Atlantic, which were reported in 1995 at a North American symposium (Atlantic States Marine Fisheries Commission (ASMFC), 1997).

this volume.) In a sense, when managers make their objectives more precise, the research community can provide more meaningful assessment of reef performance and the validity of design.

While many factors have been identified as being related to design, for economics and biology no systematic detailed assessment of the available databases has been performed. Such assessments might be a useful starting point for identifying research and management priorities to evaluate, improve or create designs of artificial reefs.

Finally, in the biological sciences many reports are based on short-term studies. It may now be useful to plan longer term research that is more intensive in determining how the life history requirements of individual species are met by artificial habitat. This would involve manipulation of biotic and abiotic variables to determine response of organisms.

(5) Acknowledgements

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