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ADVANCES IN KNOWLEDGE AND PRIORITIES FOR RESEARCH, TECHNOLOGY AND MANAGEMENT RELATED TO ARTIFICIAL AQUATIC HABITATS

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The reasons for use of artificial structures to create habitat for fishes and invertebrates, and/or enhance fisheries have only strengthened since they were enumerated by Buckley et al. (1985) in an introduction to the proceedings of the Third International Artificial Reef Conference. Evidence of accelerated worldwide interest and effort in this field is provided by comparison of that conference, held in 1983, and the Fourth International Conference on Artificial Habitats for Fisheries, for which this paper provides a program summary and introduction to the technical proceedings. For example, in 1983, 43 presentations and 14 posters described research and technology in seven nations, whereas in 1987, 94 oral reports and 37 posters depicted effort in 19 countries (Seaman, in press).

In this paper we report highlights of research, technology and some management according to the conference sessions in which information was presented and discussed. A more general summary of all 1987 conference events is provided in newsletter format (Seaman and Welch, 1988), and one of the special sessions is reported in a volume of abridged papers (Reggio, in press). Planning, sponsorship and additional comparisons with three previous conferences are described by Seaman (in press).

The overall purpose of the conference was to organize and evaluate research and development intended to enhance aquatic habitat and therefore fishery populations in freshwater and marine ecosystems. Although utilization of artificial aquatic habitats has occurred for centuries, scientific description of their function and impact has been only recent (Bohnsack and Sutherland, 1985). To some degree, inquiry in freshwater and marine systems represents different bodies of knowledge which the conference sought to unify, although most information came from estuarine and oceanic settings.

Overview of Global Efforts

Centers of activity for artificial habitats for fisheries include portions of Australia, Japan, southeastern Asia, the Caribbean and eastern and northern Mediterranean basins, the Pacific Islands, and North America. Much of the effort is focused on coastal marine environments, although lake, reservoir and lotic freshwater systems are also addressed. The papers and abstracts in these proceedings review planning and programs in certain geographic areas, as well as results of research and development in individual nations and at specific sites.

Interest in manmade habitat has gone beyond benthic artificial reefs to include structures deployed at various depths in the water column (i.e, fish aggregating devices, or FADs). Experience with both broad types of habitat has been gained by major user interests, including commercial seafood harvesters, artisanal fisheries, and recreational interests. Environmental management interests, meanwhile, continue recent evaluations of bottom reefs as mitigation for habitat alteration or loss.

Planning at a national level is restricted to at most a few governments. Japan continues to be the most technologically sophisticated in terms of extensive de-

ployment of specifically designed massive structures in pursuit of national goals for commercial seafood production in territorial waters. In contrast, the United States plan provides a framework in which numerous state and local governments and private interests work autonomously, largely in pursuit of private recreational fisheries (and some diving) objectives, with virtually no federal expenditure for deployment.

Seafood harvest is clearly the primary objective of most habitat creation efforts worldwide, in artisanal and more industrial settings. Most commonly, materials are acquired opportunistically from surplus manmade or readily available natural products, such as concrete block or brushpiles, respectively. Only in Japan has a large infrastructure of commercial reef-building interests developed.

Increasingly, artificial reefs and other structures are viewed as fishery management tools for use in concert with other practices. A particular concern is that deployment of reefs and FADs should be accompanied by regulations restricting fishing effort and gear at the structures. Rather than being used in isolation strictly to enhance exploitation of populations aggregated for harvest, artificial habitats may serve conservation purposes. For example, reefs have been deployed in Monaco and Thailand to prevent trawling in certain inshore habitats. Reefs to serve as reproduction or nursery sites are used for a number of species in Japan, and in the United States include lingcod spawning (Washington) and spiny lobster refuge (Florida). Fishing effort in urban areas in Washington has been relocated away from heavily utilized natural reefs, by creating reefs for pier and boat facilities.

Advances and Priorities

Growth of a multidisciplinary database for artificial aquatic habitats has accelerated in the mid-1980's, primarily on a spatial basis as additional investigators have initiated research and technology transfer at new geographic locations. Conversely, long-term study has been conducted at only a limited number of sites. Gradually, descriptive studies are being augmented by more quantitative efforts. Despite various individual studies of benthic reefs during the modern history of fishery science, with increased effort in recent years (Bohnsack and Sutherland, 1985), this field is still relatively new. For example, assessment of both economic impacts as well as certain ecological parameters has been initiated only in about the last decade, and indeed rigorous techniques still are in development. Bohnsack and Sutherland (1985) determined that in multi-year periods in 1966–1983 the average number of peer-reviewed artificial reef publications ranged between 4.4 and 8.0 annually, principally in natural and engineering sciences.

At the Fourth International Conference on Artificial Habitats for Fisheries technical sessions were organized both for subjects of historical interest with a more extensive literature (i.e., ecology, engineering, fishery management, mitigation) and for new areas (i.e., techniques of environmental assessment and monitoring, economics and policy, conversion of obsolete petroleum platforms to permanent fishery habitats, artisanal fisheries). These are summarized below, not as annotated accounts of all presentations, but with reference to trends, major findings, or identified needs:

Ecology.—This session received the most papers (21), reflecting past scientific emphasis. Evidence for in situ biological production of certain artificial reef sites and also for aggregation of organisms from surrounding habitats suggests that questions related to attraction and production cannot be cast in an "either-or" dichotomy. An updated approach would be to consider a continuum along which

attraction and production vary in relation to one another in terms of providing a source of animal populations at given locations.

Ecological characterization of benthic reefs has included description of physical conditions, such as currents, and patterns of community succession. Less information is available for FADs. Information needs include how the life history requirements of individual species may be addressed in design features of artificial habitats, especially recruitment and survival of juveniles. Study of trophic dynamics as well as the relative importance of shelter and recruitment limitation is emerging as an area of interest. Continuing needs for long-term research, rigorous experimentation, and utilization of artificial habitats as sites for more classical studies were identified.

Engineering.—Structural design and performance of Japanese reefs reflect the most intensive efforts in this field, which overall is relatively new and significantly less sophisticated worldwide. Limited experimentation and quantification has been conducted at U.S. Atlantic coast sites. Fabrication of specific reef structures is not common, in contrast with continuing widespread deployment of materials that are acquired opportunistically. There is a need to integrate biological investigations of species requirements with engineering studies of materials design, placement, and performance physically. Limited technology transfer of Japanese habitats has occurred. Joint studies, as well as evaluation of different levels of cost and complexity to achieve similar levels of biological productivity are required.

Fishery Management.—Despite limited scientific explanation of what makes a reef, FAD or other structure effective from a biological standpoint—in terms of defining how a particular physical structure meets ecological requirements of one or more given species—artificial habitats recently have gained widespread acceptance as a tool of fishery science. Moreover, their utilization in many areas, particularly in commercial or recreational fishing situations, has evolved away from an orientation of maximizing exploitation. Uses of artificial habitat in resource conservation are being assessed. Furthermore, questions about the intended goal of manmade habitat need to be answered prior to deployment.

There is some debate over the institutional and organizational arrangements best suited to plan and implement habitat programs. In many areas, private fishing interests secure and deploy materials on the basis of self-interest, whereas close governmental agency management of reef and other programs is the only avenue used for habitat enhancement in other areas.

Mitigation.—The practice of using artificial aquatic habitat to replace a natural habitat that has been impaired by human action only recently has used benthic reefs as a mitigation technique. Worldwide, as reported to the conference, apparently has occurred only on the Pacific coast of the contiguous United States mainland, where both rocky reef habitat and secondarily established macro-vegetation have been created. Management-oriented research in Washington has developed a list of "biota indicators" for use in siting reefs in temperate waters, with good assurance that a given assemblage of organisms will colonize the habitat. Testing of this index methodology in other settings, and long-term assessment of reefs as mitigation techniques, are two subjects recommended for further investigation.

Environmental Assessment and Monitoring.—This facet of reef-related research and technology has received a disproportionately small amount of effort. It has been demonstrated quantitatively that various traditional fish censusing methods,

for example, are not directly comparable. Whereas common visual assessment techniques may produce highly correlated rankings of species on reefs of similar size, estimates of actual abundance can vary significantly according to method (e.g., line transect, point census, etc.). Thus different field procedures can cause marked bias in data on fish abundance.

Additional fishery science practices that are in stages of refinement or require new apparatus include optimal size of sample area, and hydroacoustic and video sensing.

Economics and Policy.—Just as development of government policy toward artificial habitats has lagged their actual widespread deployment in the last two decades, so has policy-related research lagged the actual implementation of policy. Ownership and use patterns are variable, including private and common property holdings, and goals for food and recreation purposes. In such an extremely heterogeneous situation no uniform international policies toward reefs, FADs, and related structures have emerged. Japanese managers have declared that reef-based fisheries are operating on a long-term sustainable basis, for example, whereas in artisanal settings shorter term efforts to maximize production have not been evaluated. Impacts of artificial habitat-centered fisheries on other elements of the resource base have not been evaluated extensively. Further clarification of goals is foreseen, as reefs emerge as accepted fishery management tools, and as both their popularity and the opportunity for conflict among users increase. Economic assessment of actual performance of artificial habitats has been limited, so that unambiguous linkage of fishing and catch rates to given species has been difficult. Recent study has determined that design and location features controlled by planners are important to economic performance of artificial habitat. New research should include interdisciplinary approaches by economists, biologists and social scientists.

Artisanal Fisheries.—Artificial reefs and fish aggregating devices are frequently and successfully used to create fishing areas near artisanal villages in several nations. In the Philippines, for example, pyramid shaped artificial reefs are constructed by villagers from locally available bamboo. Current research in the Philippines is using concrete reinforced with bamboo to build reefs with an improved life span. Not only do the artificial reefs provide fishing sites but it is thought that they also help show that reef structure is valuable and hence reduce destructive fishing applied to natural reefs.

In Thailand the government has deployed a number of experimental artificial reefs near artisanal fishing villages. The reefs, made of concrete and tires, provide habitat which attracts the more commercially valuable reef related species compared to the species previously found on the soft bottom habitat. In areas heavily fished by trawlers, the artificial reefs are useful simply if they close an area near the villages to trawlers.

Petroleum Platform Conversion.—The increasing availability of obsolete offshore petroleum production platforms as potential fishery habitats has motivated efforts to demonstrate and apply this technology in areas such as the U.S. Gulf of Mexico, where about 4,000 structures ultimately face removal and planned onshore salvage. Other areas of potential application include California, the Caribbean, North Sea, and southeast Asia. Fishery harvest at in situ (operational) platforms includes recreational catch in Louisiana and Texas and mariculture of mussels and other commercial shellfish species in California. In the U.S., there is concern for delays in consideration and implementation of policies to facilitate utilization of obsolete

platforms for fishery enhancement. Meanwhile, technical engineering, economic and some biological knowledge of conversion of platforms to permanent habitat has been developed recently. There is remarkable structural similarity between platforms and certain reef units fabricated in Japan.

At a policy level, progress to allow industry to satisfactorily resolve questions of liability has been made, while domestic defense and international legal concerns remain. Emerging study needs include the impacts and alternatives of redeployment of platforms as related to fisheries benefits and existing ecosystems. (See Reggio, in press.)

General Issues.—A clear need for interaction among disciplines is apparent, wherein the objectives and impacts of artificial habitats for fisheries can be evaluated from a broad perspective that includes different user group concerns. This might ensure that goals for habitat enhancement are well-defined prior to actual deployment, and that attainment of objectives can be evaluated in measurable ways. Just as the role of reefs, FADs and related structures has broadened and gained wider credibility in the field of fishery management, continuing expansion of the types of studies of them is also warranted. For example, in the area of ecology, ongoing research regarding colonization, population size or seasonality might be supplemented by analysis of behavior or food webs.

To complement development of new knowledge of artificial habitats, education and technology transfer at lay public and semi-technical levels are required. The growing popularity of reefs, FADs, etc., worldwide warrants that science be employed in guiding new and appropriate deployment efforts to optimize benefits, and minimize costs and negative impacts. Continuing exchange of information among scientists must be accompanied by incorporation of the best available data in ongoing or planned reef and FAD construction. For example, guidance of placement of materials by U.S. recreational volunteer projects could incorporate study designs that evaluate parameters such as spacing, density and profile, thereby taking advantage of structures that might not be affordable through agency or academic budgets. Continuing effort to translate material (Haga and Vik, 1982) is required. Obviously, subsequent international conferences will draw from and enhance a growing network of interests in this field.

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