Fisheries Conservation and Habitat Improvement in Marine Ecosystems*

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Introduction

A significant challenge to aquatic sciences and resources management is to formulate responses to the twin worldwide forces of fisheries depletion and habitat degradation. The 2004 World Fisheries Congress identified two problems: “Serial depletions by area, species and trophic level” for fisheries, and “major alterations to fish habitat (that) have depleted resources in the world’s aquatic ecosystems.” Among several authors who have characterized fisheries loss was the 1999 Larkin Lecturer (coincidentally speaking in Vancouver, British Columbia, site of the Congress), who cited regional statistics of “overfishing” for 30% of species in the United States and “heavy exploitation” of 57% of fish stocks in European waters in defining its magnitude (Cochrane 2000). Habitat impairment, meanwhile, is perhaps the more diverse and less easily measured of the two situations. Among its multiple causes is nutrient enrichment, linked to a “doubling of additions of fixed nitrogen to the biosphere from human activities” during 1960 to 1980 in a review of coastal eutrophication by Boesch (2002).

To further one Congress aim of devising “a strong statement on the task of harmonizing fisheries and conservation,” certain principles, practices and measures of marine habitat improvement are considered here, as one aspect of responding to loss of fisheries and habitat. In doing so, the following discussion presents information on human-made reefs and their role—as one tool of many—in the management of both fisheries and habitat. Principal subjects covered in this paper include a definition of marine habitat improvement and determination of its attainment, the present applications of reef construction technology to environmental situations both generally and in three case-studies, and suggested desirable attributes for incorporation into future use of this technology. Our purpose also is to offer a context for related, more specific Congress papers addressing “habitat improvement” while challenging readers to consider the validity, applications and limits to artificial reef technology, a field rooted in antiquity but only recently becoming undergirded by rigorous scientific investigation.

Context for Marine Habitat Improvement

* Authors’ note: This document was the basis for a keynote presentation at the 2004 World Fisheries Congress, in a session on Marine Fisheries Habitat Improvement. Several of the slides shown there are included here, without captions.
This section establishes a context for habitat improvement by addressing the purposes for which it may be applied, technologies available for its achievement and practices for assessing performance. The question that must be stated first and foremost, prior to any actual habitat alteration is: “Improvement to what?” We maintain that it is essential that a “baseline” condition be defined by fishery and habitat scientists and managers, and other informed stakeholders, as a guide for design of a habitat improvement project and for its evaluation, and that this definition be established prior to implementation of any improvement practices. However, it should be acknowledged that whatever current "natural" conditions may be presumed for a given coastal system likely represent a "shifted" baseline given the ubiquity of historical overexploitation (Jackson 2001).

**Purposes of Habitat Improvement**

Habitat improvement may be undertaken from either a relatively pristine or a relatively degraded baseline condition. The former approach is generally termed "enhancement" and seeks to augment the natural level of productivity of a given system. Artificial reefs often are applied in this context. For example the placement of artificial reef habitat in flat sandy areas may provide for the creation of new food webs within the ecosystem, thereby enhancing overall trophic throughput. The demonstration that this approach is effective has been a severe challenge as evidenced by the attraction/production controversy (AFS 1997), although documentation of a spectrum of ecological responses is readily available in recent literature.

The latter approach is often termed "restoration". Though artificial reefs are sometimes applied in this context as well, it is important to consider a wide range of actions as habitat improvement. For example, the ambitious Greater Everglades Ecosystem Restoration is seeking to return estuaries in South Florida, USA to historical baseline conditions by restoring natural quantities, qualities, timing, and distribution of freshwater inputs that had been severely diminished and distorted by the drainage and flood control system implemented in the 1950's. This program is of interest if for no other reason than it is possibly the largest habitat restoration ever attempted in the world, with costs estimated at U.S. $8 billion (USACOE 1999) over 20 years. Efforts include filling straightened channels of a river and restoring its original meandering course and otherwise “re-plumbing” canals built originally for drainage.
Restoration to What?
Finding the Baseline in The Everglades

Restoration of The Everglades, Florida, U.S.A.

Shifted (Lost) Baseline in The Everglades
- Urbanization Has Covered Wetlands
- Oxidation of Soils Lowers Landscape

Images courtesy of M. Collins, U. of Florida
Clearly, different criteria for evaluation will apply in these two contexts for habitat improvement. For enhancement, the goal to be evaluated could be viewed as "more fishery yield than was present before the improvement". For restoration, the goal is to restore some prior condition of ecosystem structure, function, and/or yield. Here, the challenge is in defining what that prior condition looked like (as it may have existed so long ago that no one remembers) and in determining if that historical baseline is a reasonable goal given the possible loss of resilience in a given system. In the Everglades example, elevation changes over the landscape due to soil oxidation and subsidence in drained wetlands make the historical condition of freshwater flow impossible to restore, even if these areas were converted back to wetlands. Also, a substantial portion of the system is now in urban development. Thus, extensive simulation modeling has been used to define approximations to the historic condition that are deemed attainable and still provide for human needs of flood control and water supply to extensive urban areas.

Habitat Improvement Technologies

In sum, the practices addressed in this paper involve purposeful placement of either human-made or natural materials in a benthic marine ecosystem, generally on the coastal shelf or in an estuary, with a goal of modifying ecological structure and function. Recent methods and research for artificial reef development have been reviewed in, among other sources, reports from the most recent international scientific conference on the subject (ICES 2002) and compilations of regional research and development (e.g., Europe--Jensen et al. 2000). Its aims can be broad and multi-faceted or quite limited, and may include individual or combined physical, biological and socio-economic objectives. Our assessment is that reefs can be employed as a management tool to address both of the concerns noted in the Introduction, namely (1) to resolve certain fishery stock issues (e.g., establishment of nursery and reserve areas, protection of essential habitat from physical disturbance), as well as (2) in the more visible activity of creating physical habitat where biological production is expected to occur (in a way that mimics natural processes). However, extensive knowledge of population and/or ecosystem function as well as careful planning and implementation are required to accomplish either of these goals.

The role of artificial reef technology in mainstream Fishery Science to achieve these goals still may be under debate, even as its applications in this sector increase and its scientific underpinnings are strengthened. Beyond the scientific community, this technology is being embraced by a growing number and variety of practitioners, according to both geography and purpose. Thus, we indicate the breadth of the field as a reminder to the Fishery Science profession that numerous interests, perhaps allied only loosely to it, nonetheless have a stake in its practices in scores of countries bordering tropical and temperate seas. Additional goals, therefore, beyond the immediate fishery habitat purview of this
paper, include: Aquaculture, either on a limited site (e.g., Italy) or in the broader context of marine ranching (e.g., Korea); promotion of biodiversity (e.g., Monaco); enhancement of scuba recreational diving (e.g., Canada); eco-tourism development, using submersible vehicles to visit designed reefs (e.g., Mexico, Bahamas); expansion of recreational fishing (e.g., Australia); artisanal and commercial fisheries for seafood (e.g., India, Japan respectively); and research (e.g., United Kingdom).

Indicators of Progress

In a discussion of the attributes of ecological restoration, a working group of the Society for Ecological Restoration and the IUCN Commission on Ecosystem Management addressed “indicators of restoration progress” in stating that “an ecosystem is considered to be fully restored when it contains sufficient biotic and abiotic resources to sustain its structure, ecological processes and functions with minimal assistance or subsidy” (Summary Record, Ecosystem Restoration Working Group, 2-5 March 2003, unpublished). Against this framework, the evaluation of aquatic restoration frequently has lagged. For estuaries, for example, while a large number of wetlands restoration and creation projects have occurred since 1980, monitoring data and evaluation in terms of performance criteria remain problematic (Desmond et al. 2002). Only recently has the field of artificial reef technology begun to emphasize definition of clear measurable objectives and utilization of consistent practices to measure progress toward objectives (Seaman 2000).

Restoration of Marine Habitats

The following three case studies are presented as a guide to current and emerging considerations for habitat improvement. In each situation, the goal addresses actual restoration of a degraded system, as opposed to enhancement of a relatively pristine system. These examples are provided from Atlantic, Indian and Pacific Ocean biogeographic regions and reflect a diversity of goals including restoration of plant habitats, bivalve mollusk systems and fisheries stocks.

Restoring Oysters in Ecosystem Context

The Chesapeake Bay on the eastern coast of the US is an example of a large system with a drastically shifted baseline over a fairly long historical time period. As early as 1881, a wide survey of Chesapeake Bay oyster (Crassostrea virginica) beds determined that "overworked" beds had reduced structure, increased amounts of sand and mud, and were composed of 97% broken shell and debris as compared with 30% for unfished beds (Wilson 1881 cited in Kennedy and Breisch 1981). Oyster catch in the Chesapeake Bay has been on a general decline from its peak in 1874 (14 million bushels) to less than half a million bushels in recent years. The current stock of oysters in the Chesapeake Bay is estimated to be approximately 2% of the historic baseline.
The continuing declines in oyster abundance and oyster reef habitat occurring throughout the 20th century have been coincident with other (possibly related) modes of habitat degradation such as declining water quality (e.g., increased turbidity, eutrophication, and anoxia). These declines led to cascading disturbances such as loss of seagrass habitat due to turbidity and additional oyster losses to disease. Because oysters are filter feeders, there has come to be wider acceptance that the loss of oysters (along with land-based pollution) may have been a factor in this water quality decline (Coen and Luckenbach 2000). Hence, restoration of habitat (including conducive water quality, seagrass, and oyster reefs) in this system may depend on maintaining a certain biomass of filter feeders in the system. Traditional oyster habitat restoration approaches focused narrowly on providing low artificial shell reefs to attain fisheries goals, i.e., increasing harvestable oysters. This approach has not met with success, as continued overharvest and anoxia events have not yielded increased habitat quality or productivity (Lenihan 1999, Coen and Luckenbach 2000).

A more recent scientific consensus (e.g., Coen and Luckenbach 2000 or see website [http://noaa.chesapeakebay.net/habitat/hab_oyster.htm](http://noaa.chesapeakebay.net/habitat/hab_oyster.htm)) is emerging that, for artificial oyster reefs to constitute effective habitat improvement, they need to be taller (i.e., provide more structurally complex habitat and a potential refuge from bottom anoxia events) and they need to be protected from harvesting in order to provide for persistence of the reef structure and the maintenance of sufficient oyster biomass both for filtering and for reproductive capacity (Coen and Luckenbach 2000). Recent research modeling the effects of bivalve filtering (oysters and clams) on turbidity in Chesapeake Bay has provided the prediction that maintaining an average oyster biomass of 25 g/m² would reduce turbidity by an order of magnitude, greatly increasing the amount of light reaching the bottom and thereby expanding the suitable area for seagrasses habitat (Newell et al. 2003). Such modeling research provides specific quantitative goals for planning and evaluating habitat improvement.

**Kelp Mitigation**
A more focused example involves the creation of a large kelp (*Macrocystis pyrifera*) bed as mitigation for habitats destroyed in the coastal Pacific Ocean by the operation of the San Onofre Nuclear Generating Station in southern California, USA. In this case, the operators of the electrical power plant were mandated to create 61ha (150 acres) of new kelp bed habitat off site from the one that was destroyed. Thus, off site mitigation has aspects of both restoration (replacing the function lost at the old site) and habitat enhancement (creating new productivity in the new site).

The placement of artificial reefs is one component of this project. However, the project managers chose to begin with a moderate sized 8.9 ha (22 acres) pilot project to gain assurance that an appropriate design for the full-scale reef would yield the habitat characteristics and functions legally required by the mitigation permit. Thus, a set of experimental reefs with different substrate characteristics (quarry rock vs. concrete, different coverage of hard substrate vs. sand) or other actions (e.g., transplantation of kelp) are undergoing extensive evaluation to determine the degree of habitat improvement for fishes and benthic communities provided. Specifically, the successful recruitment and growth of giant kelp (or survival and growth of transplants) onto the artificial reef structure is the primary point of concern. Very specific quantitative goals have been laid out including those related to physical structure (e.g., % cover of rock vs. sand in the artificial reef patches), biotic habitat (kelp and other benthic species) and fish communities (Reed et al. 2002). Some of these performance standards are in terms of an absolute historic baseline (i.e., the total amount of kelp that was lost – ultimately 61 ha [150 acres] at a density of 4 adult plants/100m²). Others are stated relative to current status of other similar habitats in the area. For example, fish assemblage, recruitment, and production should be "similar to natural reefs in the region" (Reed et al 2002).

Over the first two years of monitoring the experimental reef, kelp recruitment has been successful and both kelp density and fish recruitment (i.e., young-of-year juvenile fish density) compare favorably with natural reference reefs. This suggests that habitat improvement has indeed been accomplished, though monitoring will continue over a five-year period. (See website http://www.sce.com/sc3/006_about_sce/006b_generation/006b1_songs/default.htm.)

**Fisheries Restoration**
The third of our case studies of (structural/physical) responses to habitat and fishery degradation includes the most emphasis on simulation modeling of ecosystems, fishing and policy, and is the newest, from Hong Kong, China. There, high trawling effort during the last quarter of the 20\textsuperscript{th} century produced declining catch, high fishing mortality, greater relative capture of low-value short-lived species, and virtual elimination of longer lived demersal species of higher value (Pitcher et al. 2002). After a peak fishery harvest of over 240,000 tonnes in 1989, catch in 1998 was under 145,000 tonnes, due both to high exploitation and to habitat loss and disturbance (Wilson et al. 2002). In response a multi-faceted approach including fishing licenses, protected areas, and restoration and enhancement of habitats was proposed; a five-year Artificial Reef Programme started in 1996, funded at U.S. $13,000,000, as discussed by Wilson et al. (2002). (See also website http://www.artificial-reef.net/English/main.htm.) These latter authors described the planning and implementation process, consultations with stakeholders and preliminary results for reef ecology studies including documentation of juvenile fish recruitment for species of Sparidae and Lutjanidae, residence of adult Serranidae, and increased catch of small-scale fisheries for bream (Sparidae).

In brief, deployed vessels (including along park boundaries to prevent trawling), rock, tire units and concrete units (28,000 m\textsuperscript{3} total) were located in two marine parks, according to a voluntary no-fishing arrangement made possible by placement of additional artificial reefs for fishing in open mud areas. An area of 10\% of Hong Kong waters has been set aside as a “Fisheries Protection Area.” According to predictions by Pitcher et al. (2001) the value of the fishery would increase by over 50\% if 10 to 20\% of waters were managed on a no-take basis.

Forecasting the responses to this artificial reef-based fishery restoration project was done by Pitcher et al. (2002), using three ecosystem and resource models. Information from a variety of local databases and consultations allowed these authors to incorporate (1) diet, growth and mortality data for 255 reef-associated and non-reef fish species, sorted by size, and collected into 27 functional groups, and (2) descriptions of seven sectors (e.g., trawling) of the Hong Kong fishery into “Ecosim” and “Ecopath” models. In turn, these provided the basis for dynamic “Ecospace” simulations to predict fishery performance according to fishery sector and habitat. In contrast to a non-reefs scenario that depicted continuing depletion of the fishery (e.g., five of 27 functional groups reduced to almost zero after 10 years) and increase of lower-trophic level organisms, an actual increase of harvest of large reef species was observed.
fish is forecast when artificial reefs are deployed. In one situation, the authors forecast a total catch of reef fish of 100 tonnes per year, including 60 tonnes of large demersal reef fish.

This situation represents an early and significant application of ecosystem simulation to artificial reef performance and coastal fishery/habitat restoration. Pitcher et al. (2002) note both the advantages of such an approach, including the capabilities for analysis of trade-offs among marine protected area and reef deployment design practices and for comparison of policy options, and also potential concerns including levels of confidence and uncertainty.

Conclusion

Here we describe certain trends in habitat restoration as manifested in the preceding three case studies. First, in contrast with many typical artificial reef deployments that have relatively small areal “footprints,” such as individual ships or “patch reefs” of concrete modules, each is being implemented on a relatively larger scale, from a 61ha (150 acres) site in California to marine parks in Hong Kong to virtually the entire Chesapeake Bay (64,000 square mile) watershed. Comparisons of these three restorations are summarized in Table 1.

Table 1. Components for enhancement of fishery habitat restoration performance.

<table>
<thead>
<tr>
<th>Component of Habitat Development</th>
<th>System</th>
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<tbody>
<tr>
<td>1. Goal/performance measure</td>
<td>Oyster reefs</td>
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<tr>
<td></td>
<td>Oyster biomass=25g/m$^2$;</td>
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<td></td>
<td>monitoring in progress</td>
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<td>2. Ecosystem context</td>
<td>Kelp forests</td>
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<td></td>
<td>4 plants/100m$^2$;</td>
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<td></td>
<td>monitoring in progress</td>
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<td>3. Ecological basis for design</td>
<td>Reef fisheries</td>
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<td></td>
<td>Increased fishery yield;</td>
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<td></td>
<td>monitoring in progress</td>
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<tr>
<td>4. One tool of many used</td>
<td>Oysters as critical component</td>
</tr>
<tr>
<td></td>
<td>of ecosystem to enhance water</td>
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<td></td>
<td>quality; opportunity for</td>
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<td></td>
<td>recovery of other habitats</td>
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<td></td>
<td>(e.g., seagrass)</td>
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<td>5. Advanced techniques</td>
<td>Adjacent natural reefs as</td>
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<td></td>
<td>reference target and</td>
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<td></td>
<td>source of recruits</td>
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<td></td>
<td>Considers adjacent natural reefs</td>
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<td>and open mud and sand</td>
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</table>

Secondly, each situation includes the measurable objectives necessary to successful implementation of aquatic ecosystem restoration. Both the Chesapeake Bay and San Onofre efforts specify units of oyster biomass (25 g/m$^2$) and plant density (4/100 m$^2$), respectively, while the Hong Kong program is more general in seeking increased fishery catch. In all cases monitoring to acquire data for measurement of performance is in place. Further, ecology of organisms has been used to direct design of reef structures.

In all cases, also, reefs are being used in two broader contexts. As a fishery management tool, for example, they are coupled with new fishing license measures in Hong Kong. In a broader ecosystem context meanwhile, management of nutrients from the Chesapeake Bay watershed along with oyster
reef restoration and protection to enhance filtering are expected to improve water quality and increase
opportunity for seagrass bed recovery. The southern California kelp bed project is explicitly
quantifying recruitment of kelp, other benthic species, and fishes in a spatially explicit way, cognizant
of the importance of the mosaic of surrounding habitats for reference and as a source of recruits.

Finally, the use of pilot studies to test reef designs (kelp) and ecological modeling to predict reef
function (oysters, Hong Kong) represents an effective step in maximizing success of the projects
through rigorous scientific study design. We suggest that marine habitat and fishery restoration and
enhancement now under consideration or planning could benefit from the approaches of these three
systems (Table 1.).

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