Selecting sites for large-scale deployment of artificial reefs in Hong Kong: constraint mapping and prioritization techniques

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We describe the site selection process for artificial reef deployment within an ambitious programme initiated by the Government of the Hong Kong Special Administrative Region to restore fisheries resources and rehabilitate the marine environment. The process was focused on identifying six optimum locations by employing constraint mapping and prioritization criteria. Constraint mapping involved the identification of areas of incompatibility between artificial reefs and existing uses as well as future potential sites. Broad environmental, socio-economic, and cost-efficiency prioritization criteria were applied to the unconstrained areas so that a short-list of the six highest priority sites could be defined. The combination of constraint mapping and prioritization criteria ensured that sites acceptable to a wide range of user groups were selected.

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Introduction

In an effort to reverse the declining trend in fishery resources and to balance the impact of urban and industrial expansion, the Government of the Hong Kong Special Administrative Region has embarked on an ambitious artificial reef programme (Wilson et al., 2002), involving an extensive consultation round with stakeholders (Clarke et al., 2002) and a detailed siting study to precede the actual construction and deployment phase. We focus here solely on the issues concerned with the identification of suitable sites for artificial reef deployment. In Asia, many previous artificial reef siting exercises failed through incorrect siting (Chang, 1985). This has resulted, for example, in deployment in areas that are too exposed to wave action, resulting in the break-up of the reef structures or where reef units have subsequently subsided into very soft sediments (Tian, 1998). Geophysical and hydrodynamic factors are only two of many issues of concern in selecting suitable sites. There are also constraints resulting from other human activities such as intensive fishing, shipping, and waste disposal. We present a case study of how constraint mapping and a broad range of site selection criteria have been applied in a way that was tailored to the Hong Kong situation.

Programme goals

Planning procedures in artificial reef programmes have often, despite recognition of the need to plan in a long-term and broad fashion (Bohnsack and Sutherland, 1985), been site- or project-specific (Gordon, 1994). In as broad a programme as that envisaged for Hong Kong, the first generic rule in planning must be invoked, i.e. to identify the programme goals. Through consultation with various groups (Clarke et al., 2002), four generic
goals were identified: (1) to enhance marine resources; (2) to rehabilitate degraded habitats; (3) to protect spawning, nursery, and marine protected areas; and (4) to enhance habitat quality in open seabed areas. By agreeing these goals with key stakeholders, sites could be selected that addressed one or more of the goals. Budgetary constraints required that the six highest priority deployment sites should be identified. This was conducted through firstly excluding constrained areas and secondly prioritizing remaining areas. No reef design information was used in the site selection process as it was decided a priori that the reefs should be engineered once suitable sites had been identified. This approach was adopted because engineering could then be tailored to the specific goals of a site and the prevailing environmental and geophysical conditions. Other studies (e.g. Heaps et al., 1996) more typically involve a process of selecting a site suitable for a previously specified reef design.

Constraint mapping

Constraint mapping techniques have long been used in site selection studies to bring together environmental, economic, and social considerations in an overall assessment (Gordon, 1994; Heaps et al., 1996). This is achieved through the collation of layers of mapped information showing features, constraints, and engineering or planning proposals, to produce a multi-layered constraint map that forms the basis for the identification of the unconstrained areas. The approach provides a means of taking account of potentially damaging environmental effects in a structured and rigorous way, particularly when the capabilities of a modern computer-assisted Geographical Information System (GIS) are utilized. The exercise was initiated by identifying the constraints to be taken into account. For each constraint, it was then necessary to decide how this information should be portrayed. A series of coloured “overlays” was used to indicate the constrained areas, thus revealing the remaining unconstrained areas in which further investigations were focused. The remaining locations became, in essence, the regions of study for identifying constraint, it was then necessary to decide how this information should be portrayed. A series of coloured “overlays” was used to indicate the constrained areas, thus revealing the remaining unconstrained areas in which further investigations were focused. The remaining locations became, in essence, the regions of study for identifying the identification of potential reef sites.

Broad preliminary screening criteria were applied to identify and exclude areas of incompatibility between artificial reefs and existing and planned future uses. These incompatible areas were principal fairways and major shipping lanes, existing and potential port facilities, future reclamation areas, seabed cables and tunnels, which combined resulted in the exclusion of 374 km² (20%) of Hong Kong waters. The second step was to overlay areas, which, although having future potential, would either not be available for use in the deployment planning horizon of 2002 or for which pilot tests or other research would be required owing to uncertainties over impacts. Unavailable areas were mariculture areas, breakwaters and seawalls of future reclamation areas, active marine borrow areas and mud disposal sites, seabed pipelines, existing and potential sewage outfalls, and existing marine parks and reserves. These were removed from further consideration, resulting in the exclusion of a further 280 km² (15%). Thus, the total area excluded comprised 35% of Hong Kong waters, the majority of which was located in the central Harbour area and the waters north of Lantau Island (Figure 1).

The unconstrained areas were divided into 22 potential sites according to approximate geographical and natural boundaries (Figure 2). Upon close scrutiny, a further five areas were excluded as they were either very shallow, located near to seabed scour holes, too small to contribute to the goals of the programme or located too close to existing mariculture zones (Sites A–E). The remaining 17, long-listed sites, were considered potentially able to fulfil the goals of the programme and were subjected to further analysis to identify the six highest priority sites.

Prioritization

A series of environmental, socio-economic and cost-efficiency criteria were used for prioritization. To ensure a consistent means of evaluating priorities, a categorization system were applied using either positive (“+”) or negative (“−”) signs to reflect the degree of site suitability. While all sites on the long list were regarded as unconstrained, prioritization criteria were designed as a basis of ranking sites along a gradient of suitability.

An evaluation of (−−) indicated that the site was not suitable because the cost and/or practicality of the special and unanticipated engineering, design, or management features required to overcome drawbacks would likely be prohibitive. For example, a site located far offshore in an area exposed to typhoon storms would be expensive to construct and logistically difficult to monitor. In contrast, (+++) indicated that the site was highly suitable and did not have any apparent drawbacks. For example, a site located in an area favoured for deployment by local fishing communities would be highly suitable as it is more likely to be effective. Each site was evaluated separately in its own right, rather than relative to the other sites on the long list. Thus, any number of sites could be assigned the same category ranking, and all sites, or none, might be classified as suitable. Sites were then assigned a rank under each group of criteria in relation to the number of “+++” or “−−” they received. The Rank 1 site for each group of criteria would generally have received predominantly “+++” and few if any “−−”. All sites receiving a Rank 1 were assigned four points, Rank 2 three points, Rank
3 two points and Rank 4 one point. The three scores (environment, socio-economic, cost-efficiency) were then summed and the most suitable sites were those with the highest total score. The three categories received equal weighting, as sites can only be suitable if they are ranked highly within all three groups of criteria. The criteria within each group were chosen with reference to those presented in Gordon (1994) and Heaps et al. (1996), but modified for the Hong Kong situation taking into account the limitations of data sets available.

Environmental criteria

Opportunities for habitat restoration (Goal 2). Sites which were regarded as highly suitable according to this criterion were those in close proximity to exhausted or closed sand dredging and mud disposal grounds.

Potential increases in stocks of high-value species (Goal 1). Sites that presently support stocks of high-value fish (groupers, snappers, grunts, sweetlips, and seabreams) or represent habitats for juveniles would stand to benefit most from reef deployment and thus were given a high priority. Catch reports from a recent stock assessment study (ERM, 1998; Pitcher et al., 1998) were used as the basis for evaluation.

Water quality and hydrography. Existing environmental conditions may affect the lifespan and effectiveness of artificial reefs. Areas with high suspended solids, turbidity, or low dissolved oxygen levels, were not prioritized. Hydrographic conditions, exposure, and topography may also contribute to reducing effectiveness, for example by making the site unsuitable as a spawning ground. Sites with high seabed-current speeds and high susceptibility to wave action were given a lower priority rating.

Degree to which local rocky habitat is limited (Goal 4). By providing high-profile heterogeneous habitat where it is currently limiting, marine resources that depend on this type of habitat may be enhanced. The percentage of rocky outcrops in the selected sites was evaluated from recent geophysical surveys and charts.

Benefits to other ecosystem components: Sites that offered additional potential benefits, such as prey for marine mammals and seabirds or fragile habitat, were prioritized.

After applying the environmental criteria, West Sokos and Ninepins received Rank 1, because they offered...
the potential to rehabilitate degraded habitats, enhance open seabed areas, and had no major environmental drawbacks (Table 1).

**Socio-economic criteria**

**Conflicts with existing fishing operations.** One of the issues raised by fishermen during consultations (Clarke et al., 2002) was that existing fishing areas on which fishermen are particularly dependent should be avoided. Accordingly, areas characterized by a high degree of dependence (in terms of time spent fishing, catch weight, and number of vessels) were not prioritized.

**Degree of community support.** Success of managing marine habitat is greatly dependent on the support of local people, particularly fishermen’s groups (Russ and Alcala, 1996), because, if lacking, a 24-h enforcement presence may have to be maintained. Sites preferred by fishermen during consultation fora (Clarke et al., 2002) were accorded higher priority.

**Recreational opportunities.** The degree to which the local community might use the reef for recreation was also considered. Sites that would provide opportunities to use, enjoy, and learn about the natural environment were given a higher priority. Such opportunities might include new fishing grounds (under permit) for sport fishermen and new attractions for SCUBA diving clubs. Sites were evaluated against information from local government publications and consultations with diving clubs and sport fishers.

After application of the socio-economic criteria, only East Po Toi was given Rank 1, because it was the only site where fishing conflicts were unlikely (Table 1).

**Efficiency and cost-effectiveness**

**Ease of management.** A prime factor for government’s consideration is how efficiently and cost-effectively artificial reefs can be monitored and managed. Natural features of coastlines (e.g. a bay versus an open-sea site) may facilitate monitoring and enforcement. Similarly, proximity to presently managed areas would be favourable as resources are already devoted to policing, and the community is aware of management practices. Consequently, a site near a Marine Park or Reserve may be easier to manage. A further factor was distance from the coast. This issue is of particular concern owing to reports of illegal fishing activities (even dynamite) by fishermen from mainland China (Sham, 1998).
Consequently, siting a reef close to the mainland may threaten its long-term viability.

Cost of construction, deployment and maintenance. Where hydrographic or geological conditions are less favourable, a higher degree of engineering for unit preparation (stronger construction) or site preparation (stabilization of sediments) would be required. Because extra engineering would increase costs, sites requiring special design features were not given high priority. Sites close to shore or port facilities were considered to have reduced costs of construction, deployment, and maintenance.

Benefits to the local economy. The degree to which reef deployment would affect the local economy in the long term was also considered. Information on catch weight, vessel numbers, dependency, gear type was analysed to identify ports or villages which operate small-scale/artisanal fishing gear suitable for exploitation of enhanced fish stocks on or around the reefs and thus would derive the greatest benefit. Fishing communities of mainly trawl fishermen are unlikely to benefit because their operations will be restricted. Therefore, sites nearby small-scale fishing communities were given highest priority.

After application of these criteria, South Brothers, Shek Kwu Chau, Inner Port Shelter, Outer Port Shelter, Tolo Channel, and Tap Mun received Rank 1 (Table 1).

Overall ranking

Upon completion of the scoring process, the five sites with the highest scores were, Shek Kwu Chau (#4) and Outer Double Haven (#17), Ninepins (#7), Tap Mun (#15), and Outer Port Shelter (#10), while there was a tie for the sixth position between West Sokos (#3) and East Po Toi (#6) (Table 1). However, two of these sites (Outer Double Haven and Tap Mun) are very close to existing Marine Park-based deployment sites (ERM, 1999). To avoid clustering a large number of reefs within a small area, these two sites were not carried forward to the proposed short-list, which allowed the selection of one remaining site from those with a score of 4. Of these sites, only Shek Ngau Chau (#16) was included in the top four ranks in two categories (environmental and socio-economic categories) and hence was recommended as the sixth site for the short-list.

The short-list was presented to stakeholder groups at the second stage consultation fora (Clarke et al., 2002). Concerns were raised over the boundaries of the Shek Ngau Chau site as potential for conflict was identified between the reefs, permitted fishing vessels, and container traffic to a mainland Chinese port to the north. In response, site boundaries were moved to the south and west (Figure 3).

Discussion

The application of constraint mapping to exclude areas of incompatibility coupled with the use of a series of environmental, socio-economic, and cost effectiveness prioritization criteria resulted in the selection of six high-priority sites that satisfy a priori goals for artificial reef deployment. The sites at Shek Kwu Chau and Outer Port Shelter should help to protect spawning and
nursery areas. East Po Toi and West Sokos are located on former sand dredging sites and reef deployment there offers the potential to rehabilitate the habitat. In deeper waters, Ninepins and Shek Ngau Chau have the potential to enhance habitat quality of open-sea areas by providing high-profile hard-bottom habitat.

The GIS mapping technique applied allowed sequential layering of constraints from digital data and subsequent identification of unconstrained areas. To prioritize sites located in these areas, a ranking system was used that qualitatively judged how suitable a site would be in respect to specific criteria. This approach to site selection has relied heavily on the relative availability of information available. Fairly extensive databases of environmental research publications, government reports and grey literature were used to strengthen the scientific rationale for the site ratings. The list of criteria applied was by no means exhaustive. Heaps et al. (1996) and Gordon (1994) present more extensive lists. However, our list was tailored to the Hong Kong situation and the limitations of the available information. The prioritization process, although supported by documented information, was essentially a qualitative system. The advantages were that there was no need to constrain the number of criteria to be examined or to introduce weighting factors. Assigning weighting within a group of criteria and among groups is obviously difficult. If type of reef to be deployed and its specific objectives would have been known, one criterion might assume importance over another. However, our approach was to find sites that were generically suitable and to incorporate established techniques in reef design later to ensure that reef units were tailored to the specific needs of a site. Assuming each factor has equal weighting ensures that no one factor exerts undue bias to the selection procedure. This also applies when comparing between environmental, socio-economic, and cost-efficiency criteria. Thus, the sites selected are the most suitable of the three groups of criteria combined without trading off one interest against another. The criteria within each group were of uneven number, but by working with an overall score for each group the problem of undue weight to one issue was avoided and effects of any double counting were kept to a minimum.

Although our approach was tailored to the Hong Kong situation, constraint mapping followed by a rigorous site selection procedure might be applied generically to artificial reef programmes elsewhere in the world.

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