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An integrated environmental risk assessment and management framework for enhancing the sustainability of marine protected areas: The Cape d'Aguilar Marine Reserve case study in Hong Kong

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HIGHLIGHTS

- A scheme is designed to assess environment risks in marine protected areas (MPAs).
- It can systematically evaluate the elements that affect the sustainability of MPAs.
- Cape d'Aguilar Marine Reserve of Hong Kong is employed to illustrate the method.
- Most significant components are identified for protecting the integrity of the MPA.
- The results can improve decision-making and conservation of marine biodiversity.

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ABSTRACT

Marine protected areas (MPAs), such as marine parks and reserves, contain natural resources of immense value to the environment and mankind. Since MPAs may be situated in close proximity to urbanized areas and influenced by anthropogenic activities (e.g. continuous discharges of contaminated waters), the marine organisms contained in such waters are probably at risk. This study aimed at developing an integrated environmental risk assessment and management (IERAM) framework for enhancing the sustainability of such MPAs. The IERAM framework integrates conventional environmental risk assessment methods with a multi-layer-DPSIR (Driver–Pressure–State–Impact–Response) conceptual approach, which can simplify the complex issues embraced by environmental management strategies and provide logical and concise management information. The IERAM process can generate a useful database, offer timely update on the status of MPAs, and assist in the prioritization of management options. We use the Cape d'Aguilar Marine Reserve in Hong Kong as an example to illustrate the IERAM framework. A comprehensive set of indicators were selected, aggregated and analyzed using this framework. Effects of management practices and programs were also assessed by comparing the temporal distributions of these indicators over a certain timeframe. Based on the obtained results, we have identified the most significant components for safeguarding the integrity of the marine reserve, and indicated the existing information gaps concerned with the management of the reserve. Apart from assessing the MPA's present condition, a successful implementation of the IERAM framework as evocated here would also facilitate better-informed decision-making and, hence, indirectly enhance the protection and conservation of the MPA's marine biodiversity.

1. Introduction

Anthropogenic activities can result in a broad range of adverse impacts upon coastal marine environments and thereby cause a degradation of the ecosystem services that it provides (Halpern et al., 2008). Marine protected areas (MPAs) are increasingly being established to conserve marine ecosystems, through protecting habitats, facilitating the recovery of over-exploited stocks and degraded areas, and resolving user conflicts (Toropova et al., 2010). Since the First World Conference on National Parks (1962), the number of MPAs around the world has increased substantially to more than 5850 in 2010. In 2010, MPA coverage has reached over 1% of the total global sea area, of which only 0.01% are marine reserves (i.e., no-take areas) (Wood et al., 2008; Toropova et al., 2010).

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Although MPAs are universally supported as an important tool for the conservation of marine ecosystems and biodiversity (at all levels), their effectiveness and sustainability remain controversial (Boersma and Parrish, 1999). The achievement goals for MPAs are determined by many factors, including management plans, legislative requirements, enforcement, research and education. In practice, MPAs shield marine organisms within their boundaries but do not guarantee protection from threats to the marine environmental quality (Mwangi et al., 1998). For example, it has been demonstrated that even no-take areas can be threatened by the contamination of various toxic chemicals such as persistent organic pollutants (POPs) and trace metals (Campanella et al., 2001; Terlizzi et al., 2004), which originate from surface runoff, partially treated effluents, freshwater discharges from polluted rivers and/or contaminated atmospheric depositions. Given that some MPAs are situated in close proximity to urbanized areas and influenced continuously by anthropogenic activities such as untreated and partially treated wastewater discharges (Siracusa et al., 2001), marine organisms inhabiting such MPAs are, as a consequence, at risk. An effective and pragmatic environmental risk assessment (ERA) and management framework is, therefore, deemed necessary for the sustainability of such MPAs.

Both chemical and non-chemical stressors should be addressed during a comprehensive environmental risk assessment (ERA). By definition, an ERA is a process that combines risks from multiple sources, stressors, and routes of exposure for humans, biota and ecological resources in one assessment (USEPA, 2002). The ERA process was established originally to assess the risks of chemical contaminants to human health and the environment. In the United States of America in the 1980s, ERAs mainly targeted the toxicities of single chemicals to human health (USNRC, 1983) and was modified subsequently to evaluate the impact of chemical contaminants on ecosystems (Suter, 1993; USEPA, 1998). Given their history, the most previously conducted ERAs mainly dealt with the environmental risks associated with single, multiple or groups of chemicals, but seldom considered the co-existence of other non-chemical stressors (Landis, 2003). In contrast, the European Union's Environment and Health Strategy adopts a broader approach that integrates information obtained from scientific research, environmental health, the environmental effects and fate of pollutants, and seeks views from different stakeholders prior to policy making (CEC, 2003), although there has been little elaboration of how ecological and economic risk estimates can be either considered or weighted during the decision making process (Thomas et al., 2012). There is, hence, a challenging demand to extend chemical-oriented ERA to embrace non-chemical stressors and link their risks with ecological, social and economic factors.

A comprehensive evaluation of multi-sectoral risks facing MPAs is important and should integrate socio-economic dimensions into ecological research for MPA management (Thomas et al., 2012). As a multi-sectoral approach, the DPSIR (Driver–Pressure–State–Impact–Response) framework, based on the concept of a "chain of causation", considers both environmental and socio-economic impacts on the marine environment (Ojeda-Martinez et al., 2009). This heuristic methodology is being employed increasingly among researchers and policy-makers for structuring and communicating environmental policies because it is highly flexible and suitable for projects of different natures such as fisheries management (Mangi et al., 2007), a feasibility study on offshore wind power facilities (Elliott, 2002) and the integrated coastal zone management of multiple beneficial uses (Pastres and Solidoro, 2012). The DPSIR model for assessing either water quality or the effectiveness of MPAs has been a common tool in the management of MPAs (Ojeda-Martinez et al., 2009; Beliaeff and Pelletier, 2011). They provide, however, insights only into the development of indicators and cause–effect relationships, but not explicit ecological risk assessment methods or applications of the developed indicators. In this sense, a vigorous, yet practical, integrated environmental risk assessment and management (IERAM) framework is still lacking for MPAs. In this study, we develop an IERAM framework for MPAs by integrating a newly-constructed multi-layer DPSIR model with the conventional ERA approach.

Our proposed IERAM framework includes screening mechanisms for various stressors to MPAs, the objective identification of stressors with unacceptable risks, and formulation and prioritization of management options with consideration of both ecological and socio-economic dimensions. To illustrate the IERAM framework, the Cape d'Aguilar Marine Reserve of Hong Kong, China is used as a case study. The marine environmental problems described in this case study would be similar to those encountered by other coastal metropolises where MPAs are located in proximity to urbanized areas. This case study will, thus, generate essential information for future deployment of IERAM frameworks in the management of coastal marine environments and MPAs.

2. Description of the case study site

Cape d'Aguilar is situated on the southeastern tip of Hong Kong Island in the Hong Kong Special Administrative Region (SAR) of China. In 1995, the Hong Kong Government, recognizing the importance and urgency of protecting the geomorphological and ecological environment of Cape d'Aguilar, designated this area as the first and, to date, only marine reserve in Hong Kong (Fig. 1). Morton and Harper (1995) published a holistic seminal introduction to the Cape d'Aguilar Marine Reserve, providing important information on the geology, coastal geomorphology and broad ecological significance of the multiple habitats encompassed by the borders of this tiny reserve. The marine reserve has a rich marine biodiversity, with numerous habitats such as intertidal sea arches and subtidal caves (zawns), hermatypic and ahermatypic coral reefs, exposed and sheltered rocky beaches, cobble beaches, intertidal pools of varying dimensions and elevations, and protected underboulder landscapes (Morton and Harper, 1995). This reserve is considered to be of immense scientific and environmental significance for Hong Kong, which enables it to be managed as a single ecological unit under the protection of the Hong Kong Marine Park's and Reserves Ordinance 1995 (Cap. 476). Due, however, to its small size (0.2 km^2) and location in close proximity to sources of human activities, the management for protection and conservation of this reserve may not be effective without a dedicated survey and assessment of the impacts of such human-derived perturbations.

3. Methodological approaches

Fig. 2 outlines "A multi-level assessment approach" within a framework that combines qualitative and quantitative approaches to the different steps of the assessment process. Such a preliminary approach was developed to obtain an overview of the risks involved and their prioritization for the further management of the Cape d'Aguilar Marine Reserve.

3.1. First step: identification of potential threats — linking MPAs to broader coastal areas

MPAs can be affected profoundly by human activities that lie outside their boundaries, ranging from marine transportation and fishing to land-based marine pollution. MPAs are often designed and managed without recognition of the larger marine system within which they are located. A variety of economic and social activities taking place outside a MPA need to be identified and geographically mapped, therefore, for further risk assessment of the MPA. Activities that threaten the sustainable uses of the marine environment and effectiveness of the Cape d'Aguilar Marine Reserve include (Fig. 1):

- Contamination from land-based activities, such as inputs of chemical and bacteria through sewage treatment plants, which can pollute the MPA;