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MANAGEMENT FOR LONG-TERM SUSTAINABILITY OF MARINE HABITATS IN SINGAPORE: A SCIENCE-BASED APPROACH

Nigel Goh
Coastal & Marine Environment Programme Office, National Biodiversity Centre, National Parks Board, 1 Cluny Road, Singapore 259569, Republic of Singapore
Email: Nigel_Goh@nparks.gov.sg

ABSTRACT. – Long-term sustainability of biodiversity and natural habitats is a common global objective. In the complex and constrained physical, socio-economic and political environments present in Singapore, the need for a science-based approach to management is more acute. This management approach is illustrated in the Singapore experience in terms of maintaining up-to-date biodiversity baselines, minimizing impacts from coastal development works, enhancing survey and monitoring methodologies and maximizing survival potential of existing biodiversity. Many aspects of this approach could be adapted for other tropical coastal cities; however, in the face of increasing physical and socio-economic pressures, the science-based approach needs to be closely integrated with other management approaches to ensure coastal habitat sustainability in the long term, especially with challenges from increasing urbanization and global climate change.

KEY WORDS. – Sustainability; urbanization; biodiversity, conservation, science, Singapore.

INTRODUCTION

Strategies for long-term sustainability of marine habitats, particularly in environments shared with humans, require a good understanding of the physical, socio-economic and political environments and circumstances relevant to the habitats. Without consideration of these factors, such strategies could become overly theoretical, and consequently either impractical or unsustainable. As a minimum, management constraints like physical limitations, the sometimes-conflicting priorities of different stakeholders, as well as the limited nature of options available, need to be considered and addressed realistically.

In developing such strategies, several management approaches, many of which are not mutually exclusive, can be considered. Such approaches as applied to uses of marine habitats include: (a) a policy of decision-making that consciously seeks to keep as many use-options as possible open; (b) maintaining continuity in staff/organizational memory related to management of such habitats, and (c) integration of concerns and priorities among stakeholders. Often, more than one such approach needs to be applied for successful long-term habitat sustainability. In the last five years, a key approach in Singapore has been to leverage on the strengths of science to inform, guide, and inspire management decision-making.

MAJOR SUSTAINABLE HABITAT MANAGEMENT CONSTRAINTS

Sustainable habitat management measures need to be implemented in the context of specific constraints that differ from locality to locality. In Singapore, some of these constraints include historical impacts on habitats, limited land area, and the presence of multiple stakeholders with often conflicting priorities.

Historical impacts. – Modern-day Singapore was founded by Stamford Raffles in 1819, who recognized its strategic location and natural harbour. The British East India Company capitalized on these assets and developed an economy based on trade, and hinged on the provision of good port facilities to support that trade. Since then, much of Singapore's coastline has been transformed from its original mangroves and coral reefs to one dominated by the world's busiest container port, as well as other coastal developments. A greater part of the original shoreline has been reclaimed, especially in the south, where most of the island's coral reefs are found. It has been reported that an estimated 60% of Singapore's original reefs have been lost or impacted (Chou, 2007; Tan et al., 2007). However, the same analysis by Chou (2007) noted that while abundances may have declined, species richness appears to have remained stable for the last four decades. It is interesting that few confirmed marine extinctions are known from the marine environment while those on land are far more substantial (see Tan et al., 2007, for a review).

Physical size and socio-economic realities. – Singapore has a land area of about 700 km^2 and a population of some 4.8 million (Statistics Singapore, 2008). This translates into a population density exceeding 6,800 persons per km^2. Economic development, housing, recreation and other quality of life aspirations of this population have to be considered in use of limited land and coastal resources, including marine habitats.

Multiple stakeholders. – Singapore has a large number of stakeholders within its limited coastal area, each with a different jurisdiction or interest in coastal and marine habitats: various government agencies are responsible for different aspects of coastal land and sea-space use; some private corporations manage coastal facilities; academic and nature groups also contribute knowledge and add their voices to this already diverse stakeholder community.

NEED FOR PRAGMATIC AND INNOVATIVE APPROACH

The various constraints illustrated above lead to a situation where feasible options available to Singapore for long-term sustainable management of marine habitats are limited, and the needs of all stakeholders have to be balanced against real constraints.

Some 'limitations' arise from a simple lack of knowledge. These constraints can actually be addressed immediately using existing technology and management tools. The gaps are only in awareness and implementation.

Other 'limitations' are based more on self-constrained paradigms (especially the belief that the priorities of habitat conservation and those of economic development are 'zero-sum' in nature – the extent of one's win is more or less the extent of the other's loss), rather than on real constraints. A more pragmatic mindset, which is able to envisage and implement solutions that will benefit more than one party, albeit to a compromised extent, is needed. In the creation of the Semakau Landfill in 1997, the natural vegetation on the original Pulau Semakau, as well as the extensive seagrass beds and coral reefs to the west of the island were not developed/reclaimed. From an optimal land-use for landfill point of view, this was a compromised position. On the other hand, good quality mangroves on the east of the island were allowed to be directly covered up; however, compensatory planting of mangroves at the north and south of the original Pulau Semakau made up to some extent for the mangroves lost. In a win-lose situation, stakeholders become adversarial rather than collaborative – for long-term sustainable management of marine habitats, stakeholders need to move from a stance that is protective to one that is more forward-looking and proactive.

There is a constant need to question current 'limitations'. Where limitations are real, innovative solutions should be explored. One of the major ecological impacts on marine habitats in Singapore arises from the high ambient level of suspended sediments in the water. Addressing this problem has been confined to controlling the rate of increase in suspended sediments. Lowering the ambient levels of suspended sediments had been considered impractical because of the sheer volumes of water involved. However, with an innovative mindset and new advances in water technology, a project was initiated in 2009 by the National Parks Board, in partnership with the DHI-Nanyang Technological University Water and Environment Centre and Research Hub to investigate techniques to reduce sedimentation in large, open bodies of water. Scientists agree that if sedimentation in the water can be reduced, hard coral cover on our reefs is likely to increase (L. M. Chou, pers. comm.). This example illustrates that science is able not just to define and measure problems; science can also contribute in very tangible ways to come up with solutions to current constraints.

ROLE OF SCIENCE IN MANAGING SINGAPORE'S MARINE HABITATS

Sustainable coastal management is dependent on good decisions and rational trade-offs in the use of resources. In the context of Singapore, with multiple stakeholders and limited space, this can be an especially complex exercise. Good, reliable information that science can provide is therefore required.

Coastal management in such a complex and constrained environment needs to be dynamic and forward-looking, constantly searching for new ways to challenge constraints and maximize resources, while maintaining relevant good practices. Scientific methodology and technological advances can provide the basis for such solutions, and some examples of their application in Singapore are described below:

Maintaining up-to-date Biodiversity Baselines. – Information on the biodiversity present at a particular site ('biodiversity baseline') is fundamental to good management and establishes the reference point for measuring impacts to biodiversity habitats. In Singapore, basic coral reef, sea grass, and mangrove biodiversity baselines have been established, and are used in coastal management decisions. For example, knowledge of the rich marine biodiversity at Labrador Nature Reserve resulted in a major change in reclamation profile of a planned port expansion at Pasir Panjang that commenced in 2007. The ability of these baselines to correctly represent the prevailing condition of biodiversity at any particular site is critical to well-founded decisions being made. This information is kept up-to-date by regular monitoring surveys.

The baseline itself is renewed continuously. Various studies by the two major tertiary institutions, NGOs and government agencies are constantly adding to the data. For example, an unpublished 2008 study of the taxonomy and distribution of intertidal sponges yielded 40 new locality records for

Singapore, and potentially one species new to science. Other initiatives, such as the 2006 marine biology workshop, co-organized by the National University of Singapore's Tropical Marine Science Institute, and Department of Biological Sciences, together with the National Parks Board (results of which are presented in this volume), brought experts from around the world to focus short-term but concentrated efforts to better understand local biodiversity, have helped to significantly raise the level of baseline knowledge.

***Minimizing Impacts from Coastal Development.* –** Where physical development works in Singapore having potential impacts on marine habitats are assessed to be necessary, habitat-related environmental quality objectives (EQOs) are set for these development projects. Among other things, EQOs are based on the biodiversity baselines mentioned previously. The biodiversity baseline establishes the reference point for measuring impacts to biodiversity habitats. Similar baselines/EQOs are also maintained/set for other environmental parameters related to water quality and hydrodynamics. These EQOs ensure that marine habitats are protected from impacts beyond their tolerance thresholds. EQOs were set based on tolerance limits of marine habitats at key sites like Labrador Nature Reserve and Tanjong Rimau for recent projects like the Pasir Panjang Terminal expansion and the Pulau Ular Reclamation.

Monitoring surveys to document changes in biodiversity baselines are carried out throughout the duration of the development project and continue after its conclusion to ensure compliance with the EQOs set. These surveys also contribute to the maintenance of current biodiversity baselines.

A common consequence of coastal development is an increased amount of suspended sediment in the water surrounding the development site. In Singapore, a real-time suspended sediment feedback system has been developed. This system comprises in-situ turbidity sensors coupled with a hydrodynamic model incorporating ambient environmental information (Doorn-Groen, 2007), and is used regularly to maintain suspended sediment in water at acceptable levels. This allows control to be based on the actual level of suspended sediment rather than on indirect factors like the rate of dredging or soil dumping.

***Enhancing Survey and Monitoring Methodologies.* –** The Line-Intercept Transect (LIT) method for monitoring coral reefs is an internationally established technique for quantifying the reef flora and fauna dominated by hard corals. LIT results from the reef crest have been considered representative of coral reef health and diversity, and used in management decisions. However, local research has shown that a rich abundance of organisms dominated by non-scleractinian fauna exist at depths below the reef crest (Goh & Chou, 1994, 1995; Goh et al., 1997). Taking this research into account, a 'Lower Reef Survey' that estimates the rich sponge, ascidian, soft coral and gorgonian fauna has been incorporated in management-related surveys and decision-making since 2006. This allows management decisions to take into account a better representation of the actual species diversity and abundance situation present.

Another limitation of using the LIT to monitor changes for control purposes related to man-made impacts is that it has a significant lag-time (weeks-months time scale) between impact and its ability to detect change. A study was recently initiated by the National Parks Board, with the National University of Singapore and DHI Singapore Pte Ltd as partners, to explore the use of pulse-amplitude modulation flourometry (PAM) technology to detect impacts on hard corals at the hours-days time scale. This method has been quite widely used to measure photosynthetic efficiency in terrestrial plants, but has yet to be applied in coral monitoring programmes.

***Maximizing Survival Potential of Existing Biodiversity.* –** Fragmentation of hard coral colonies occurs continuously on coral reefs, whether naturally or by anthropogenic action. Building on years of research on artificial reefs and coral recruitment (Chou, 2007), a conservation-focused coral nursery was established in Singapore in July 2007 as part of a partnership between the National Parks Board, the National University of Singapore, the National Environment Agency and Keppel Corporation, the latter a major private conglomerate. Besides studying fragmentation patterns, this project aims to rehabilitate broken-off coral fragments (collected from reef bottoms throughout Singapore) at the coral nursery, then transplanting them back to natural reefs to enhance natural coral populations.

Continuous recruitment of hard corals is crucial for the long-term survival of these organisms in Singapore. In addition to substratum availability, such recruitment is determined by larval dispersal patterns (which in turn is influenced by local hydrodynamics and larval behaviour). A study of larval dispersal patterns in Singapore was commissioned to provide information on the genetic connectivity between different reefs in Singapore. Tay et al. (2008) have provided some preliminary findings. Conclusions from this study will enable management actions (like enhancement transplantation from the coral nursery) to be targeted where it will have the greatest impact.

***Broad Strategic Directions for Biodiversity Conservation.* –** In terms of long-term strategy, several imperatives have been identified for conservation in Singapore – not just for marine habitats, but also for those on land or in fresh water – and all have been informed by a foundation of science. Given the size and multiple-use constraints discussed earlier, priority is given to protection of ecological habitats that represent the variety of indigenous ecosystems found in Singapore. Historical impacts on habitats necessitate proactive efforts in habitat restoration in addition to the more traditional protective approaches; the coral nursery and coral connectivity projects illustrate such an approach. Recognizing the importance of science, biodiversity research and research involving technological innovations that can enhance biodiversity are actively facilitated and sometimes directly supported when resources are available.

CONCLUSIONS

Science has provided information to guide decisions that impact the long-term sustainability of marine habitats in Singapore, and it is expected to continue doing so in increasing measure. At the same time, we have seen examples in this paper describing how science has also inspired innovative responses to some of the constraints facing this small island nation.

On the whole, together with foresight in planning and determination in implementation of plans, it can be said to have served Singapore well. For a location that is considered from a regional perspective to be ecologically ‘at risk’ (Tun et al., 2008), Singapore retains a rich marine biodiversity: for example, more than 250 species of hard corals, 11 species of seagrass and 31 species of mangrove trees were recorded recently (Goh, in press). Moreover, Tun et al. (2008) assessed that in spite of the potential risk, an overall increase in live coral cover was recorded between 2004 and 2007.

In a world faced with the challenges of large-scale climate change-induced loss of biodiversity and increasing urbanization, Singapore’s tropical location, highly developed coastlines and growing experience in managing its marine habitats might provide some useful lessons for other developing tropical coastal cities.

However, in the face of increasing physical and socio-economic pressures, even a science-based approach may not be sufficient by itself to enable the long-term sustainability of marine habitats in Singapore and other tropical coastal cities. A holistic, integrated approach to coastal management, taking into consideration global impacts like climate change, is needed to address the challenges of meeting this objective in the context of a growing tropical coastal city.

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