Coral Reefs in Singapore: Past, Present and Future

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Abstract:

Singapore's hermatypic coral diversity of 255 species represents about a third of the global total. This high diversity remains despite the loss of about 60% of the country's coral reefs to coastal development over the past five decades. The remaining coral reefs are exposed to coastal use pressures including sedimentation, and live coral cover has declined slowly and gradually since the 1980s. Another threat came from unregulated collection of reef fish and invertebrates for the aquarium trade, which was rampant until the early 1990s but considerably reduced since. From the mid-1990s, reef protection measures became more evident as measures were taken to reduce damage from coastal development and the management mandate of the National Parks Board expanded to include the marine environment. Climate change impacts added new management challenges when the reefs were affected by two major coral bleaching events in 1998 and 2010 that were linked to extended periods of thermal stress brought about by the El Niño Southern Oscillation events. Many scleractinian coral species together with other zooxanthellate groups such as soft corals, sea anemones, giant clams, zoanthids and corallimorphs exhibited varying degrees of bleaching. On both occasions, recovery was reasonably quick as sea surface temperatures returned to normal. Although the degrees of thermal stress were comparable between 1998 and 2010, bleaching in 2010 was less severe with up to 10% initial mortality, than in 1998 with up to 20% mortality. Interestingly, coral species such as *Acropora* and *Pocillopora* that are typically thought to be highly susceptible to thermal stress based on the 1998 observation, were found to be among the least impacted in the 2010 bleaching event. This suggests that some coral species may be able to adapt to higher sea temperatures but equally important is the effort to reduce anthropogenic stresses such as sedimentation and strengthen larval connectivity between coral reefs.

INTRODUCTION

The pristine condition of Singapore's marine environment was acknowledged by early visitors soon after the island's founding by Sir Stamford Raffles in 1819. Crawfurd (1830) described the superior beauty of the numerous southern offshore islands where most of the coral reefs were located when he sailed through in 1822. Early naturalists including Raffles observed the rich species diversity and discovered coral species totally new to science. The original specimens that were described have since been kept in zoological institutions, especially the British Museum (Chou, 2011). Apart from their scientific value, corals were also exploited for use as construction materials based on evidence of coral fragments retrieved from archaeological excavations. These were likely from fringing reefs on the southwestern coast of the main island. The rate of exploitation in the early days was not intense and the pace of development until the 1960s did not contribute heavily to reef degradation. The condition of the reefs in the 1960s still supported rich and abundant marine life. The clear waters made it possible to see healthy corals thriving in 10-metre depths.

Unregulated collection of reef species for the aquarium trade started in the 1960s and kept pace with increasing demand as the trade developed and peaked in the 1980s. The activity declined after Singapore ratified the Convention on International Trade of Endangered Species in 1986, but the damage is evident from the drop in abundance of many species, particularly reef fishes.

Singapore has since developed into one of the world's busiest ports. Over 150,000 vessel arrivals were registered in 2011 moving 531 million tons of cargo. The port waters occupy more than 80% of the nation's limited territorial waters of about 750 km^2 (Chou, 2006). Berthing infrastructure and wharves dominate the southwestern coastline of the main island. The southern sea is zoned by fairways, anchorages and vessel maneuvering areas that fill the space between the fifty-odd smaller offshore islands with their fringing reefs, scattered mostly in the south.

DEVELOPMENT AND MANAGEMENT CHALLENCES

The pace of development in the coastal and marine environment increased rapidly from the 1960s with mega land-reclamation projects that transformed the coastal seascape. Land reclamation obliterated about 60% of the country's coral reefs (Hilton & Manning, 1995). Coastal development including the dredging of shipping lanes and the dumping of earth spoils, which were implemented without impact assessments until the late 1990s. These activities introduced a high volume of sediment to the sea, reducing water visibility from ten metres in the 1960s to a metre today. Reefs that escaped reclamation are however subjected to the impact of heavy sedimentation. Sedimentation retards coral growth by smothering and most importantly by reducing sunlight penetration.

The port waters are stringently managed to ensure safe shipping and prevent accidents that cause spillage of oil and hazardous chemicals. Despite these safeguards, risks remain, evident from the list of incidents that occurred between 1996 and 2006 (Tan *et al*, 2007). In October 1997, two oil tankers, the "Evoikos" and the "Orapin Global" collided in the Singapore Strait releasing 28,500 tonnes of oil, the largest spill in Singapore's history. The oil impacted the inter-tidal reef flat but not the sub-tidal reef slope. Coastal reclamation and seabed dredging alters hydrodynamic

patterns while high speed vessels generate fast waves that scour reef flats and exposed shores. Grounding of flat-bottom barges on reef flats leave large tracts of damaged corals. All these activities have an impact on coral reef biodiversity.

Today, most of Singapore's reefs fringe the southern offshore islands. Reefs along the mainland have been totally eliminated, except for a small reef community at Labrador beach. There are also a few good reef communities associated with the northeast offshore islands. Although the abundance of many species is depressed, species elimination is not that evident. Of the 255 species of hard coral recorded from the reefs (Huang *et al*, 2009), only two can by now be confirmed as locally extinct. Other reef-associated animals like seashells, giant clams, sea cucumbers and sea stars are also less commonly found because of habitat loss, degradation and the earlier unregulated exploitation.

CORAL REEF BIODIVERSITY STATUS

Exposed to the diversity of impacts, Singapore's coral reefs face three major threats: habitat loss, habitat degradation and habitat modification. Historical records depict a rich biodiversity (Chou, 1994) and despite the varied and persistent impacts, new records of species not previously known to occur are still being made today. This is easily explained by the lack of exhaustive taxonomic investigations due to the difficulty of engaging experts. Taxonomic groups such as reef fishes and molluscs that were historically well documented give reliable records of past biodiversity, and impact assessments can be deduced from what has since been lost. For most groups that were well studied in the past, the indications are little to no decline in species richness, but an evident depreciation of abundance.

The general trend for reef biodiversity is that while species elimination is less than expected, the frequency of occurrence and abundance of many species have been much reduced (Chou, 2006). The high species diversity of hard corals represent almost one third of the global coral diversity. This is significant considering the limited extent of the country's reef area, estimated to be less than ten km^2.

At the same time, newly created habitats from coastal development continue to provide an alternative environment for marine species, although the new conditions may favour other species over those that thrived in the original habitat. Southeast Asia is recognized as the global centre of marine biodiversity and Singapore's location entitles it a fair share of this rich heritage. A healthy species list however, does not provide a guarantee against biological richness decline. While marine species extinctions are less compared to terrestrial species, they have occurred and biodiversity conservation remains as important for marine species.

Most of Singapore's coral reefs at present exist as patch reefs (associated with a raised sea bottom) or fringing reefs around the southern islands. The extensive fringing reef flats of some of the larger islands were reclaimed or transformed into swimming lagoons. Until the 1970s, fringing reefs were present on the main island but they have all been buried by coastal reclamation. Apart from the southern offshore reefs, a few are present at the northeast offshore islands. The past decades of increased sedimentation resulted in loss of coral from below six metres of the reef slope and an average 34% reduction in live coral cover from the upper slope.

Coral growth is now compressed within the upper reef slope with the reef crest supporting the best reef development.

The coral community is presently dominated by foliose growth forms, which have suitably large surface area to capture as much as possible of the reduced solar energy. Branching *Acropora* corals, which dominate reefs of the region, is now uncommon in Singapore reefs because of past harvesting pressure and present environmental impacts. The intertidal reef flat supports species that can tolerate periods of exposure, examples of which are *Favia*, *Favites*, *Goniastrea*, *Platygyra*, and *Oulastrea*. The greatest coral diversity occurs on the reef crest and large colonies of *Porites*, *Diploastrea* and *Symphyllia* are present. *Pectinia*, *Turbinaria* and *Pachyseris*, which all exhibit foliose or laminar growth forms dominate the lower reef slope. Their large surface area allows them to optimise the available low light energy.

Macroalgae such as the mermaid's fan (*Padina* species), and *Halimeda* species, are abundant throughout the reef flat. The brown seaweed, *Sargassum* grows vigorously as thick bushy stands at the reef crest, breaking loose during the monsoons. Reef biodiversity includes a full spectrum of reef-associated species like soft corals, sponges, hydroids, sea fans, and an entire assortment of molluscs, crustaceans, echinoderms, protochordates and fishes. Three species of giant clams are known, *Tridacna squamosa*, *Tridacna crocea* and *Hippopus hippopus*, but their populations have declined considerably.

CLIMATE CHANGE IMPACTS

Unusual sea surface temperature elevation associated with the El Niño Southern Oscillation (ENSO) events in 1998 and 2010 affected Singapore's coral reefs on a wide scale and presented a new management challenge. In early 1998, elevated sea temperature resulted in mass bleaching of Singapore corals at a scale previously unknown. More than 90% of all corals bleached and up to 20% failed to recover after sea temperature returned to normal. In 2010, another large-scale coral bleaching occurred in response to elevated sea surface temperature, resulting in up to 10% mortality. However, differences in species mortality patterns were observed (Guest *et al*, 2012) where species that were badly affected in the 1998 event appear to be less affected in 2010 and vice versa.

Despite all these impacts, important biological processes are kept intact. Mass spawning events where many coral species synchronously release eggs and sperm or fertilized egg bundles, occur consistently during the April full moon (Guest *et al*., 2002). This is followed by a smaller event in September or October and timed to coincide with the inter-monsoon lull to improve larval survival. The pomacentrid fish species also spawn during the inter-monsoon periods (Low *et al.*, 1997).

THE FUTURE OF SINGAPORE'S CORAL REEFS

No comprehensive reef biodiversity assessments have been conducted, although long-term monitoring since 1986 indicated an overall decline in live coral cover as well as a reduction in the abundance of reef-associated invertebrates, and some isolated studies over the past three decades focused on specific faunal groups. The present coral community structure is influenced by sedimentation impacts and is dominated by foliose growth forms, which have suitably large surface area to capture as much as possible of the reduced sunlight energy.

A number of artificial reef and reef restoration projects have been initiated (Tan *et al*., 2007) and a coral nursery was established off Pulau Semakau in 2007 (Wong, 2007). The latter makes use of naturally-fragmented corals from reefs and growing them at the nursery to enhance survival and growth. On the whole, in spite of reef loss and all the impacts, species richness stays comparable with reefs in the surrounding region.

The present approach, where development takes precedence over conservation, has not resulted in drastic depletion of marine biodiversity. Newly-created and modified habitats continue to support life. Species extinction from Singapore waters is not high, as many are redistributed by the changing seascape. Ecosystem processes have not been completely overwhelmed. Seasonal mass spawning of corals, recruitment and growth patterns of other marine species all indicate that biological processes are still intact. It is therefore completely possible for port waters to be teeming with marine life and rich habitats for as long as water quality is maintained. In return, the environmental services provided by a high biodiversity will help to reduce environmental renewal costs (Chou, 2008). In this era of climatic changes, it is even more important to focus attention on the protection of marine living resources in order to minimize unnecessary anthropogenic damage and loss, as these can exacerbate the effects of climate change on the local reefs. Integrated management and strategic impact assessment are approaches relevant to Singapore's situation, with its limited but intensively used marine territory.

None of the coral reefs in the southern offshore islands are under legal protection, and the lack of an integrated coastal management mechanism has resulted in the low priority given to the protection of marine habitats until the turn of the century. The establishment of the Biodiversity Centre by National Park Board in 1994 and the expansion of its mandate to cover the marine environment has started to address the previous limitation. At the same time, the formation of an inter-Ministerial Technical Committee on Coastal and Marine Environment in 2007 with representatives from all relevant agencies provided a framework that would support an integrated management approach.

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