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Marine habitats and biodiversity of Singapore's coastal waters: A review

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ABSTRACT

Rapid and sustained coastal development, land reclamation, and intense use of surrounding waters by shipping, have changed the original land- and seascape of Singapore in the last two centuries. Reclaimed land now account for more than 30% of the current land area, with a concomitant loss of original intertidal and subtidal habitats across most of the southern shoreline of Singapore mainland as well as other offshore islands. The extent of coral reefs, mangroves, mudflats, seagrass beds, estuarine reefs, sandy and rocky shores has diminished considerably, so much so that man-made habitats such as seawalls, tidal canals, swimming lagoons and other artificial structures now form significant marine habitats in their own right. These remarkable changes in the marine environment have affected marine organisms to a greater or lesser extent, based on the very limited information available on marine habitats in Singapore prior to large-scale reclamation. However, the present extent and diversity of marine life that can be observed in Singapore today is still impressive. Much remains to be discovered and deciphered in terms of their biology and ecology. New records and species new to science continue to be described, even as new coastlines are built, and organisms continually adapt to a changing environment characterized by chronic disturbance. This review serves as a snapshot of the current state of knowledge of marine habitats and biodiversity in Singapore based on existing literature. Key threats and knowledge gaps are also highlighted.

1. Introduction

Whether considered a small island lying immediately south of peninsular Malaysia, or as the northern limit of the Riau archipelago, Singapore is part of a gateway between the Malacca Strait and the South China Sea (Bird et al., 2006). In biogeographical terms, Singapore is juxtapositioned between two of the largest marine eco-regions in the world, i.e., the Western Indo-Pacific and Central Indo-Pacific regions (Spalding et al., 2007). However, Singapore is also squarely on the shallow Sunda Shelf that is contiguous with the Gulf of Thailand, the Malacca Strait, and the Malayan archipelago. Its maritime position, considered together with its proximity to the two large landmasses comprising peninsular Malaysia to the north and Sumatra to the west, is probably responsible for the unique marine ecosystems that can be seen even today around Singapore. At the same time, the waters surrounding the city-state of Singapore are some of the most intensively utilized in the world. To sustain a population exceeding 5 million with a high standard of living, the Singapore economy relies on being a very busy container and bunkering port, as well as having significant petrochemical, ship-repair and offshore rig construction industries. These coastal and offshore facilities increasingly use seawater for cooling. However, with a limited land area to harvest rainwater, industrial and domestic demand for freshwater is also being augmented by reverse osmosis of seawater and wastewater. Offshore islands and coastlines provide public recreational amenities, exclusive residential and military training areas, as well as marine nature reserves. The large number of vessels present requires suitable anchorages and room to manoeuver without interfering with floating aquaculture farms.

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All of these activities take place in designated areas that are less than 50 km from each other.

The coastal environment in Singapore (see reviews by Chuang, 1961; Hill, 1973; Tham, 1973a; Chia et al., 1988; Chia and Chou, 1991; Chou and Chia, 1991; Chia, 1992; Gupta and Pitts, 1992; Hilton and Manning, 1995; Turner and Yong, 1999; Lu et al., 2005; Ng et al., 2007; Hutomo et al., 2010; Tan et al., 2010; Davison et al., 2012; Sin et al., 2016) is a fairly benign one. Air temperatures throughout the day and year range between 24 to 35 °C, with humidity levels nearly always well above 70%. Wave action, compared to other seashores in the vicinity, is minimal (Chew, 1974). Waves buffeting the coastlines are more often caused by wakes generated by heavy boat and ferry traffic than by local squalls (also known as barat), which are often short-lived (typically lasting not more than 2 h) but can generate winds up in excess of 100 km per hour (Choi, 2000). However, coastal habitats are subjected to the harsh heating and drying effects of the tropical sun, particularly those above the mid-tide level of the shore. On a typical sunny day, rock surfaces directly exposed to the sun can reach temperatures exceeding 45 °C (Nguyen et al., 2011), but cool down rapidly after sunset to reach air temperatures of between 24 and 28 °C at night. Seawater temperatures typically range between 27 ° and 31 °C depending on depth and time of year. Having an annual tidal range of about 3.3 m, the lower of the two low tides during spring semi-diurnal tides in Singapore (Wyrtki, 1961) is generally confined either to the early morning (May through August) or late afternoon (October through March). Hence the lower littoral zone is generally spared the more stressful conditions caused by exposure to the sun. There is also no distinct wet or dry season that is often typical of regions elsewhere in Southeast Asia, since Singapore is affected both by the Southwest Monsoon (typically May through September) and Northeast Monsoon (typically November through March), although mean monthly temperatures may be slightly lower during November and December each year (Nieuwolt, 1973).

The water column thus experiences little temperature variation either diurnally or seasonally. Similarly, salinity is generally constant in the Singapore Strait, ranging between 27 and 32 psu, essentially due to constant mixing created by the regular east–west tidal current flow experienced in that area. In contrast, the salinity in the Johor Straits ranges between 21 and 31 psu with lower salinities predominating on either side of the Causeway with relatively poor exchange (Lim, 1983, 1984a,b), often resulting in stratification. Such estuarine conditions are primarily caused by the combination of riverine input and tidal influence into the two narrow cul-de-sacs, formed by the causeway (see Fig. 1) linking Johor Bahru and Singapore island. Dissolved oxygen ranges between 5 and 8 mg L^{-1}, but supersaturation can occur during plankton blooms in the day in the Johor Straits. Mean values of total suspended solids range between 15 mg L^{-1} (Gin et al., 2000) to 23 mg L^{-1} (Tkalich and Sundarambal, 2003) and may exceed 100 mg L^{-1} during a thunderstorm (resulting from terrestrial runoff; Chatterjea, 1998; Van Maren et al., 2014) or in the vicinity of reclamation activities.

2. Marine ecosystems and associated biodiversity

Key marine habitats in Singapore were recently reviewed by Chou (2006) and Tan et al. (2010). Broadly speaking it is possible to recognize nine major natural marine ecosystems in Singapore, and a further three artificial ecosystems (see Fig. 1 for location names). **Coral reefs** are located exclusively in the Singapore Straits, either as fringing or patch reefs in the vicinity of the Southern Islands. In contrast, **mangroves** (or mangal, which includes the fauna) are most extensive on the shores defining the East and West Johor Straits. Mangroves are also present along some sheltered coastlines of larger islands in the Singapore Strait. In the foreshore of mangroves, **mudflats** are fairly common, and again they are most extensive in area in the Johor Straits than elsewhere in Singapore. **Seagrass** beds have a fairly wide distribution, and can be found both in the Singapore and Johor Straits in small patches. Perhaps by far the largest in terms of area, but probably the least understood of all the others, is the **subtidal benthic** ecosystem. Submerged, unseen and difficult to study, it is nonetheless an extensive and important ecosystem that urgently needs attention, possibly with a number of distinct, but hitherto undefined habitats. Our knowledge of the **sandy shore** ecosystem also remains much to be desired. Short stretches of natural estuarine sandy shores (most, if not all of the sandy shore along the east coast were reclaimed during the 1970s) are present on shore of the East Johor Strait and on some islands in the Singapore Strait. Natural **rocky shores** are few in number, and these occur principally in the Southern Islands, which differ somewhat in structure and composition from those remaining in the Johor Straits (e.g., on Pulau Ubin). Similarly, **estuarine reefs** of Tanjung Chek Jawa, Beting Bronok and Pulau Merambong (Malaysia) differ from the coral reefs of the Southern Islands, and are sufficiently distinct to be recognized as a separate ecosystem. They are best developed at the mouths of the East and West Johor Straits. Finally, the **water column** is major ecosystem that plays a critical role in the dynamics and recruitment of all other marine systems.

While natural ecosystems have diminished both in size and diversity, there has been a corresponding emergence in the number of artificial ecosystems that have become increasingly significant around Singapore. These include extensive **seawalls**, concrete-lined **tidal canals**, man-made swimming **lagoons**, and other artificial structures in the sea. These are important biodiversity sinks in their own right. Their ecological structure and composition will be discussed in relation to natural ecosystems.

3. Coral reefs

Despite being one of the busiest container ports in the world with significant oil refining and bunkering industries within the same confines, coral reefs are not uncommon on the shores of many islands in the Singapore Strait. Coral reefs in Singapore can generally be divided into two types: fringing and patch reefs (Chou, 1988a; Wong and Sin, 2013). The fringing reefs present in the offshore islands south of Singapore island are generally narrow (Chuang, 1977), but can be divided spatially into two main areas, the reef flat and the reef slope. Live coral cover is much lower (less than 3%) on the reef flat than on the reef slope (up to 75%; Chou, 1988b). Average live coral cover at Pulau Salu in 1980s was about 10% (Chou and Teo, 1985); however, coral cover is severely dependent upon survey location, ranging between 0% and 75% (Chua and Chou, 1992). Dominant genera on the reef flat include the massive, dessication-resisting *Porites*, *Goniastrea* and *Favites*, while on the reef slope, *Pachyseris speciosa* was the dominant species with plate-like growth form. At the reef edge, *Symphyllia nobilis* and *Diploastrea heliopora* were common at Pulau Salu (Chou and Teo, 1985). Many patch reefs (terumbu) have been reclaimed but a few extensive areas remain, including Terumbu Pandan (Cyrene Reef), Terumbu Bemban Besar east of Pulau Semakau, and Terumbu Pempang Laut east of Pulau Bukom. Patch reefs have not been studied in detail. Another method of classification divides the coral reef into the reef edge, reef slope and reef bottom (Goh et al., 1997).

About 250 species of hard corals have been recorded from Singapore, of which about 160 species are locally extant (Huang et al., 2009). Common corals that can be found in Singapore include *Pocillopora damicornis*, which is sometimes common in shallow waters in the low intertidal or upper subtidal zone, and