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Land reclamation and the consequent loss of marine habitats around the Ayer Islands, Singapore

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Abstract. Singapore is a small city-state that has grown rapidly in terms of its economy and population during the past 50 years. Almost 180 km² of coastal land required for development and infrastructure has been created through reclamation. This, however, has come at a significant cost to natural marine habitats. One example is the formation of Jurong Island, developed by the amalgamation of seven offshore islands (collectively known as the Ayer Islands) to accommodate Singapore's expanding petrochemical sector in the 1980s. Little is known of the habitats and biodiversity that these islands previously hosted hence, the aim of this study is to assess what was lost. This was achieved by reconstructing the historical extent of habitats on the Ayer Islands using GIS software applied to topographic maps of Singapore from 1969, 1983, 1993, and 2002. Map analysis showed up to 10.08 km² of coral reefs and 5.25 km² of mangrove forest in 1969, which were all lost by 2002. Anecdotal evidence suggests that, prior to reclamation, the species richness of the coral reefs around the Ayer Islands was comparable to those of other reef habitats in Singapore today.

Key words. reclamation, reconstruction, coral, mangrove, historical, habitats

INTRODUCTION

Singapore is made up of Singapore Island and over 60 smaller islands (Corlett, 1992; Yaakub et al., 2014). Since its independence in 1965, its economy and population have grown rapidly with the latter estimated to reach 6.9 million by 2030 (National Population and Talent Division, 2013). To accommodate the concomitant expansion of commerce, industry, transport infrastructure, and housing, land has been, and continues to be, reclaimed from the sea (Hilton & Manning, 1995; Todd & Chou, 2005; Lai et al., 2015). Since the first reclamation project in the 1800s, Singapore's land area has increased from 540 km² to the current 719.2 km² (Corlett, 2000; Singapore Department of Statistics, 2017). Most of the land reclamation carried out in the late 1960s to 1970s was to the south of Singapore Island (Glaser et al., 1991; Yaakub et al., 2014). Here we examine the ecological effects of the huge reclamation project required to develop Jurong Island.

Jurong Island was originally a group of seven smaller islands: Pulau Ayer Chawan, Pulau Merlimau, Pulau Merbau, Pulau Sakra, Pulau Pesek, Pulau Pesek Kechil, Pulau Seraya (collectively known as the Ayer Islands), located to the southwest of Singapore Island (Omar, 2010). The decision to merge the Ayer Islands was made to provide more space for the expanding petrochemical sector, which was identified as a potential growth engine for Singapore in the 1980s (Yang & Ong, 2004). In particular, Jurong Island was envisioned as a petrochemical hub, given Singapore's status as the world's third largest major oil-refining centre (Hing & Lee, 2009; Lui & Tan, 2001). The Jurong Island reclamation project was completed in 2009 (Omar, 2010; Today, 2009), increasing the total land area by over three times from the 9.91 km² of the original Ayer Islands to the current 32 km² (Reuters, 2010).

Approximately 60% of Singapore's original reefs have been lost to reclamation (Chou, 2006; Lai et al., 2015) and this is likely to continue to meet the needs of development (Goh, 2008). In the past, it was not uncommon for reclamation to occur without assessing the biodiversity and habitats present—the Ayer Islands is one such example. This study attempts to reconstruct the natural habitats of the former Ayer Islands through triangulation of data from various sources such as topographic maps, interviews, and newspaper articles. Our main objective was to provide quantitative and qualitative documentation of the change in land cover and habitats of these 'lost islands' from the late 1960s to the present.

MATERIALS AND METHODS

Quantitative documentation of the habitats. The fringing coral reef and mangrove forest areas around Ayer Islands were drawn based on Singapore's 1: 63,360 topographic map (Chief Surveyor Singapore, 1969) and 1: 50,000 topographic maps (Singapore Mapping Unit, 1983; 1993; 2002). The topographic maps were obtained from the Map

Resource Unit at the National University of Singapore. Owing to the difference in coordinate systems and projections used for the maps, the maps of 1983, 1993, and 2002 were georeferenced to the 1969 map for spatial comparison. Coral reef, mangrove forest, and land cover were then digitised using the software ArcGIS ver. 10.2.2 (Environmental Systems Research Institute®, 2014). Four maps depicting the change in coral reef and mangrove forest cover from 1969–2002 were created. Using the spatial analyst tool in ArcMap, the areas of fringing coral reefs and mangrove forests were calculated for quantitative analysis.

Qualitative documentation of the habitats. The second section of the study involved synthesising information from previous academic studies, newspaper articles, and photographs taken by Leong Kwok Peng, the vice president of the Nature Society (Singapore), who organised a coral translocation programme on Pulau Ayer Chawan from 1993–1995. We also discussed the impact of the Jurong Island project with two colleagues, James R. Guest and Jeffrey Low Kim Yew, who both have many years of expertise researching Singapore's marine environment.

RESULTS AND DISCUSSION

Reconstruction of the Ayer Islands using 1996, 1983, 1993, and 2002 topographic maps showed that there were extensive fringing coral reef and mangrove forest sites around them previously (Fig. 1). During the reclamation, those habitats were either removed or buried. Based on the analysis in ArcMap, there were up to 10.07 km² of coral reefs and 5.25 km² of mangroves in 1969 (Table 1). Even though the official reclamation project to amalgamate the Ayer Islands into Jurong Island started in 1995, areas of coral reef and mangrove forest were already in decline before that (Table 1).

The greatest rate of loss of mangrove forests was from 1969–1983 (Fig. 1), while the greatest rate of loss of coral reefs was from 1993–2002. The loss of coral reef and mangrove forest habitats was largely due to industrial development and land reclamation. In the early 1960s, the intertidal flats around these seven islands had already started to be in-filled and used as a foundation for future reclamation (Hilton & Manning, 1995). The faster rate of mangrove forest destruction

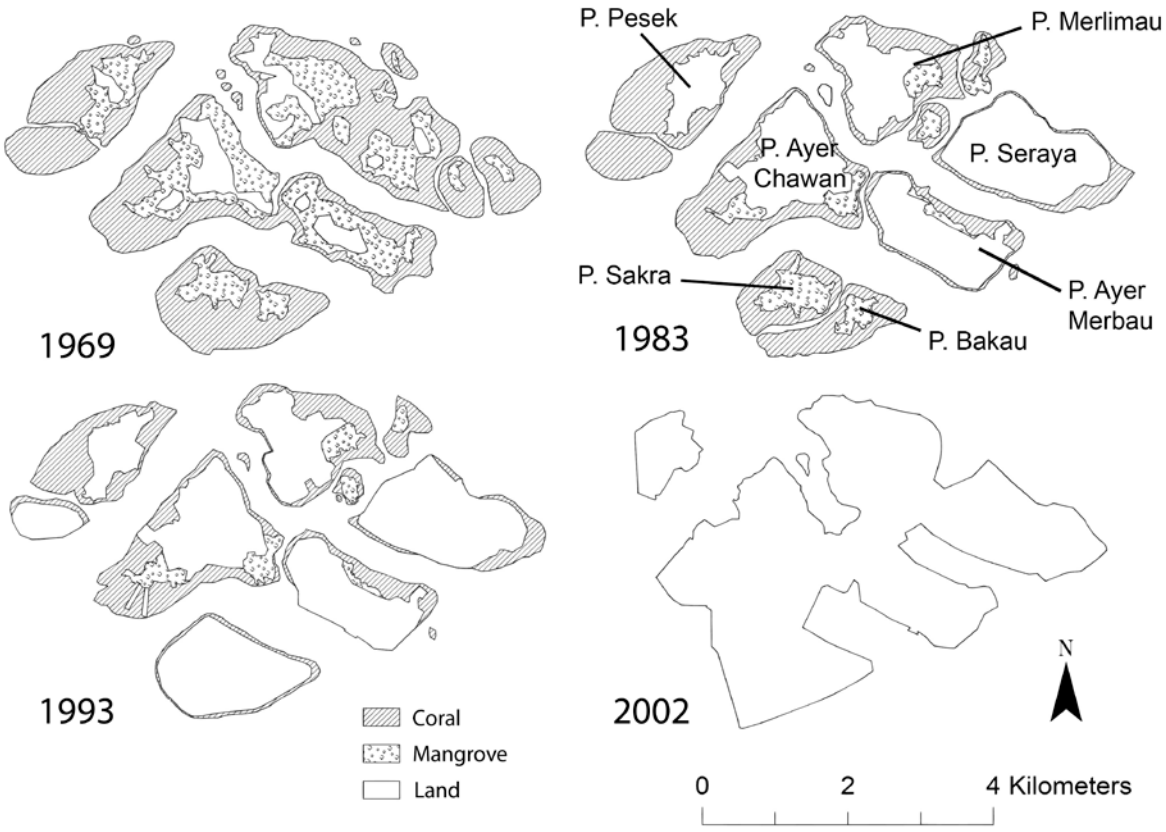

Fig. 1. Map representations of coral reef and mangroves present on Ayer Island from 1969–2002. (The universal transverse Mercator zone 48N was used for projecting the map. As Singapore is near the equator and is small, it only lies in one UTM zone which minimises the distortion of the map for computing the area).

Table 1. Areal data of coral reef and mangrove forest cover in Jurong Island from 1969–2002.

Year	Coral Cover (km^2)	Rate of Coral Cover Loss (km^2/yr)	Mangrove Cover (km^2)	Rate of Mangrove Cover Loss (km^2/yr)	Land Cover (km^2)	Rate of Land Cover Gain (km^2 yr^{-1})
1969	10.078	–	5.250	–	1.863	–
1983	7.108	0.212	1.487	0.268	7.472	0.400
1993	4.594	0.251	0.796	0.069	9.902	0.243
2002	–	0.510	–	0.088	13.348	0.382

was probably due to the building of petrochemical plants on the Ayer Islands in the 1980s as opposed to further offshore land reclamation works which subsequently decimated coral reefs fringing the islands. It is likely that mangrove forests were felled and reclaimed to accommodate the expansion of the petrochemical industries, resulting in a rapid decrement of mangrove forest cover from 1969–1983, and a parallel increment in land cover in the same period (Table 1). For both mangrove forest and coral reef cover the rate of decline to 0% cover from 1969–2002 was, on average, 3.03% of the 1969 cover lost per year. This is substantially higher than the national average, which, calculated from 1922–2011 (based on data in Lai et al., 2015), is 1.03% per year for mangrove cover and 0.79% per year for coral cover.

There are very few published papers or records of past marine habitats around the Ayer Islands, with the majority of research conducted by the private sector. Of the few academic studies, most focused on soft-bottom benthic communities (Lim & Koh, 1990; Chou, 1991; Tan & Chou, 1993). Nonetheless, investigations by Lim & Koh (1990) and Chou (1992) showed that fringing coral reefs were present. Pulau Sakra had a coral diversity of 15–32 species per 100-m transect from six survey sites around the island (Chou, 1991, in Chou, 1992). Finally, an article in The Straits Times (Nathan, 1993) stated that Pulau Ayer Chawan supported a high diversity of corals, sponges and other marine life.

Based on photographs of the reefs around Pulau Ayer Chawan taken by Leong Kwok Peng, Jeffrey Low Kim Yew (pers. comm.) identified 15 taxa: zoanthids (a types of cnidarian), the algal genera *Sargassum* and *Turbinaria*, tomato clown anemone fish (*Amphiprion frenatus*), barrel sponge (*Xestospongia muta*), and the coral genera *Echinophyllia*, *Acropora*, *Platygyra*, *Montipora*, *Pachyseris*, *Pectinia*, *Dipsastraea*, *Merulina*, *Turbinaria*, and *Plerogyra*. James Guest (pers. comm.) observed that "coral communities are dominated by sediment-tolerant taxa and growth forms such as foliose *Pectinia*, encrusting *Montipora*, and massive *Platygyra*". By the time the coral translocation programme started in 1993, sedimentation from reclamation around the Ayer Islands had already caused visibility to fall below 3 m (Nathan, 1994). Sediment pollution and associated turbidity have been a major issue for Singapore's marine life since the late 1960s (Chou, 1996; Todd et al., 2010; Guest et al., 2008; Guest et al., 2016), leading to reduced light penetration (Todd et al., 2004), coral cover (Goh & Chou, 1992), coral growth (Browne et al., 2015), and recruitment rates (Dikou & van Woesik, 2006). Hence, it is possible these deleterious effects were already occurring at the Ayer Islands prior to amalgamation.

CONCLUSIONS

This paper reconstructed the past habitats surrounding the Ayer Islands. Triangulation of information from various sources showed that fringing coral reefs and mangrove forests were the main coastal habitats present. Mapping change over the years revealed almost complete decimation of these two original habitats. The biodiversity and health of the reefs around the Ayer Islands were probably similar to those of current reefs among the Southern Islands of Singapore. It is hoped that this paper highlights the impacts of reclamation on marine habitats and the importance of conducting environmental impact assessments as part of planning, managing, and developing the coastal environments in Singapore and other Southeast Asian countries.

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