Marine Pollution Bulletin 83 (2014) 417–424

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Courage under fire: Seagrass persistence adjacent to a highly urbanised city–state

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ARTICLE INFO

Article history:
Available online 6 February 2014

Keywords:
Coastal modification
Historical distribution
Long-term monitoring
Singapore

ABSTRACT

Due to increasing development Southeast Asia's coastlines are undergoing massive changes, but the associated impacts on marine habitats are poorly known. Singapore, a densely populated island city–state, is a quintessential example of coastal modification that has resulted in the (hitherto undocumented) loss of seagrass. We reconstructed the historic extent and diversity of local seagrass meadows through herbarium records and backwards extrapolation from contemporary seagrass locations. We also determined the current status of seagrass meadows using long-term monitoring data and identified the main threats to their presence in Singapore. Results show that, even though ~45% of seagrass has been lost during the last five decades, species diversity remains stable. The main cause of seagrass loss was, and continues to be, land reclamation. We conclude that strict controls on terrestrial runoff and pollution have made it possible for seagrass to persist adjacent to this highly urbanised city–state.

1. Introduction

Coastlines worldwide are undergoing rapid urbanization and development. In East Asia alone, there are 12 coastal cities with a population of more than 15 million (Gill and Kharas, 2007) that are still expanding, placing an unprecedented strain on natural nearshore resources and habitats (Yeung, 2001). The impacts of development, such as increased pollution, eutrophication and sedimentation caused by construction, reclamation and dredging, are major threats to coastal marine ecosystems such as coral reefs and seagrass meadows (Hughes et al., 2003; Waycott et al., 2009; Grech et al., 2012). Seagrasses are habitat forming marine angiosperms that are common in shallow coastal waters. They provide a range of valuable ecosystem services (Costanza et al., 1997) but are being degraded at an alarming rate with associated reductions in their diversity, resilience and ecosystem functions (Orth et al., 2006; Grech et al., 2012). Without appropriate management, the reported widespread loss of seagrass habitats is predicted to continue (Waycott et al., 2009).

Singapore is a highly urbanized island city state located at the southern tip of the Malay Peninsula and comprises of one main island and more than 60 smaller islands. Despite her small size and limited natural resources, Singapore is an economic powerhouse in the region with a per capita GDP that rivals most of the developed world (Department of Statistics Singapore, 2013). With a total land area of 714.3 km^2 and a population of 5.3 million, Singapore is representative of the types of changes and challenges that are currently facing many other coastal cities experiencing rapid expansion and industrialization. Due to Singapore's equatorial setting and its vicinity to the Coral Triangle, it supports a wide variety of nearshore habitats including mangroves, coral reefs and seagrass meadows, all of which sustain high biodiversity (Huang et al. 2006,2009; Chou, 2008; Lee et al., 2012).

During the late 1960s to 1970s, Singapore initiated a number of large-scale land reclamation projects to ease the burden of land scarcity coupled with rapid population growth. This systematically obliterated a large proportion of coastal habitats (Todd and Chou, 2005), mostly through seaward expansion from the southeast of the main island and also the amalgamation of a group of 11 islands just off the southwestern coast. In total, land reclamation has resulted in the loss of an estimated 60% of coral reef area and 95% of mangroves (Chou, 2008) but, to date, the loss of seagrass meadows has not been documented. Mangroves are represented as forest on Singapore's maps and corals reefs are clearly delineated due to their potential as a shipping hazard. Seagrass meadows have traditionally not been treated as a navigational hazard; hence,

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http://dx.doi.org/10.1016/j.marpolbul.2014.01.012

historical records of their distribution are scarce, although they have been described as "common" on Singapore shores (Chuang, 1976).

In this paper, we examine the factors that contribute to the survival of seagrasses in Singapore's busy port waters. We explore the history of local seagrass meadows from pre-reclamation to present day through a reconstruction of their past distribution and diversity using a multi-method approach. We then determine the current state of seagrasses in Singapore through analysis of a long-term monitoring dataset for the three largest seagrass meadows. Lastly, we identify present and future threats to seagrass habitats and make recommendations for management of seagrass resources in highly urbanised coastal areas.

2. Materials and methods

2.1. Historical reconstruction

We reconstructed the distribution and diversity of seagrass meadows in Singapore by triangulating (LeCompte and Preissle, 1993) three main lines of evidence: herbarium records, topographic maps, and research interviews. We identified all seagrass specimens collected in Singapore prior to 1970 from three herbaria that were determined to have seagrass collections from Singapore: the Singapore Herbarium at the Singapore Botanic Gardens, the Herbarium Pacificum of the Bernice Pauahi Bishop Museum in Honolulu, Hawaii and the National Herbarium of the Naturalis Biodiversity Centre in Leiden, The Netherlands. From these specimens, we identified gazetteer location and species, and secondary site-specific information (e.g. sediment type, meadow size) where available. For each gazetteer location, we listed the species that occurred in that location to reconstruct meadow type and species composition, supplemented with site descriptions from den Hartog (1970). The gazetteer locations of herbarium specimens were then overlaid on maps of the Survey Department of the Federation of Malaya from 1946 and 1969. In the vicinity of gazetteer locations, we identified intertidal geographical features such as reef flats, mudflats, sand bars and sand shoals that had the potential to support seagrass growth. To explore another avenue for historical information, we sought out people that utilized seagrass meadows, including recreational and subsistence fishers, naval officers and former residents of villages that existed at locations that were near reclaimed areas, and conducted purposive interviews (Guest, 2006). We interviewed six people between the ages of 50 and 73 who fitted the above profile with the purpose of extracting information such as the approximate locations where seagrass meadows were found, their extent, how they were utilized, the time period in which they frequented these meadows and other nearby or co-occurring habitats. Respondents were given visual aids (photos of seagrass species and seagrass meadows) and presented with an old map of Singapore to help them identify areas where they utilized seagrass meadows.

2.2. Predicting seagrass extent

By overlaying the herbarium gazetteer locations and information from interviews on intertidal geographical features on maps, we were able to determine the approximate intertidal areas that supported seagrass meadows in the past (circa 1964–1970). To ensure that the historical reconstruction was representative of the full extent of seagrass, we also took into account present day distribution of seagrass in Singapore (from Yaakub et al., 2013a) and included locations that have not undergone coastline modification or reclamation, as these were likely to have also supported seagrass in the 1960s (even if they were not represented by herbarium specimens). Each location was assigned into three categories of seagrass meadows using species composition, habitat type and geomorphologic association: i.e. sand/mud flat, fringing reef, and reef platform. These categories were based on an earlier assessment of seagrass meadows in Singapore (Yaakub et al., 2013a) and in accordance with previous studies (Carruthers et al., 2002; Waycott et al., 2004).

The intertidal area for each site was estimated using ArcGIS® data (Environmental Systems Research Institute) from a 2011, 1:20,000 map. The boundary for each intertidal sand/mudflat and reef platform followed that which was demarcated on the map. For areas that have been reclaimed, we calculated the lost area from a 1946 1:63,360 map of Singapore, using the squares method after Hilton and Manning (1995). As it is unlikely that seagrass would occupy the entire intertidal area, we calibrated the extent of seagrass by applying an occupation estimate. This was obtained by dividing the actual area of seagrass meadow by the actual size of the intertidal area in order to obtain an occupation proportion. We calculated the occupation proportion from existing literature for Singapore (Yaakub et al., 2013a) supplemented with additional field mapping of eight seagrass meadows and obtained an average that is typical of each of the three meadow classifications established in the previous paragraph. This occupation proportion was then applied to the intertidal areas identified earlier to obtain a retrospective estimate of seagrass extent in Singapore.

2.3. Seagrass-Watch monitoring data

Status and trends in present-day Singapore seagrass abundance were determined over five years of monitoring (2007–2012) using the Seagrass-Watch protocols (McKenzie et al., 2009). Seagrass-Watch is a participatory monitoring program, a component of which encourages citizen science by empowering people with the knowledge and skills needed to collect data using scientifically rigorous methods. In Singapore, the data are collected by TeamSeaGrass, a group of trained volunteers collaborating with the National Parks Board. In 2007, three monitoring locations: Chek Jawa, Pulau Semakau and Cyrene Reef (Fig. 1) were established within intertidal seagrass communities at locations representative of Singapore's varying habitat characteristics e.g. island fringing reef, coastal/estuarine lagoon and patch reefs. These are also three of the largest seagrass meadows. Within locations, 2–3 replicate sites (50 m $\times$ 50 m), 200–250 m apart, were permanently marked with stakes and GPS coordinates and surveyed 3–4 times per year (every 3–4 months).

At each site, during each monitoring event, observers recorded the percent seagrass cover within a 50 cm $\times$ 50 cm quadrat every 5 m along three 50 m transects, placed 25 m apart, running perpendicular to the shoreline. A total of 33 quadrats were sampled per site. Details of the Seagrass-Watch monitoring protocols are described in McKenzie et al. (2000, 2003). Data collected from each survey was compiled and submitted to Seagrass-Watch HQ where program scientists checked them for compliance and provided an independent assessment of their accuracy and quality. For this study, we averaged the above ground percent cover data for each of the three locations to obtain a general trend of seagrass cover between 2007 and 2012.

2.4. Vulnerability analysis

A vulnerability analysis (VA) was conducted in July 2012 during a workshop with 39 participants from Singaporean academic and research institutions, government agencies and non-government organizations. Workshop participants had backgrounds in biology, ecology and management of coastal areas and worked or intended to work on seagrass habitats around Singapore. Workshop