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THE DIVERSITY AND DISTRIBUTION OF SEAGRASS IN SINGAPORE

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ABSTRACT. — Seagrasses were once common on Singapore's shores but, unlike their coral reef and mangrove counterparts, their diversity and extent have never been rigorously documented. This study quantifies the species richness and distribution of seagrass in Singapore waters through herbarium specimens and on-site surveys. We also use remote sensing to map in detail the three largest seagrass meadows in Singapore: Chek Jawa Wetlands, Pulau Semakau, and Cyrene Reef. These maps represent essential baseline data for future conservation management.

KEY WORDS. — seagrass, Singapore, remote sensing, Chek Jawa, Semakau, Cyrene Reef

INTRODUCTION

Seagrasses are flowering plants that are commonly found in both tropical and temperate coastal waters (Green & Short, 2003). They have a widespread distribution that encompasses every continent except Antarctica, but the highest diversity of seagrass species is centered in the tropical Indo-Pacific (Waycott et al., 2004). Seagrass habitats are an important component of the marine environment, providing vital services such as nutrient cycling, food provision, and climate change mitigation (Orth et al., 2006; Waycott et al., 2009). Similar to other marine ecosystems, seagrass habitats are under threat from human activities such as coastal development and increased nutrient input. These impacts have brought about accelerated decline in seagrass habitats globally (Waycott et al., 2009).

Seagrasses were common in Singapore up to the late 1950s and early 1960s, with large meadows found off the eastern coast of Singapore Island and around some offshore islands (Chuang, 1961; Johnson, 1973). The World Atlas of Seagrasses lists 11 species present in Singapore waters (Green & Short, 2003), but there is a general paucity of published information on local seagrass diversity and ecology, especially in the scientific literature (Ooi et al., 2011). In fact, they are so poorly studied that in an initial assessment of the national conservation status of plants and animals, five of the 11 species of seagrass were listed as locally extinct (Turner et al., 1994), while a later survey only found seven species spread across 12 locations (Loo et al., 1996). Even more elusive than species diversity is information on the distribution and extent of seagrass habitats in Singapore's coastal waters. This is possibly owing to the fact that seagrass habitats, unlike their coral reef and mangrove counterparts, have never been a feature in marine navigational maps, making even an estimate of their true extent difficult to determine.

It is generally acknowledged that in order for sound management of resources to exist, there needs to be an inventory and a baseline of those resources (Chua, 2006). While these exist for other marine habitats in Singapore such as coral reefs (Burke et al., 2002) and mangroves (Yee et al., 2010), there is currently no reliable baseline available for seagrass habitats. Hence, the aim of this paper is to provide a comprehensive checklist for the diversity of seagrass species and a baseline for their distribution. We also map the extent of the three largest remaining seagrass meadows in Singapore.

MATERIAL AND METHODS

Seagrass diversity and distribution in Singapore. — To determine their present distribution, herbarium records of all seagrass species (families Hydrocharitaceae and Cymodoceaceae [formerly Potamogetonaceae]) lodged with the Singapore Botanic Gardens Herbarium (SING) since 2000 were compiled and sorted by area (Eastern and Western Johore Straits, Southern Mainland, Southern Offshore Islands, and Southern Patch Reefs). Data from surveys carried out between 2007 and 2010 were used to corroborate herbarium specimens.

Extent of Singapore's three largest seagrass meadows. — The three largest seagrass meadows in Singapore were chosen for mapping (Fig. 1) as these are regularly monitored sites under the Seagrass-Watch programme

(McKenzie et al., 2009). One meadow is found near Pulau [=island] Semakau, an offshore island southwest of Singapore Island (1°12.54′N, 103°45.40′E). The island is a conglomerate of two islands, Pulau Semakau and Pulau Sakeng, combined to create an offshore landfill. The eastern shoreline was largely undisturbed during the construction of a 7-km rock bund that joins the two islands, but substantial tracts of mangroves on the northern and western side of the island were destroyed (Chou & Tun, 2007). Another is at Chek Jawa Wetlands, a mudflat situated on the eastern tip of Pulau Ubin, off the northeastern coast of Singapore (1°24.56′N 103°59.52′E). This site is influenced by the Johor River, which discharges a high sediment load into the area. The seagrass meadow at Chek Jawa is situated within an intertidal lagoon, with seagrass growing on the periphery of the lagoon on the seaward side. The third meadow is located at Cyrene Reef and refers to a group of three patch reefs, the largest being Terumbu [=reef] Pandan (1°15.52′N 103°45.27′E), which has a substantial seagrass meadow growing on the reef top. The reefs are situated just off Pasir Panjang Container Terminal and are bounded by the oil and petrochemical refinery islands of Pulau Bukom to the south and Jurong Island to the west.

WorldView-2 satellite images (1-m resolution) from 2010 and 2011 were used to map the extent of the three seagrass meadows. These were supplemented by Geoeye-1 satellite images when cloud-free Worldview-2 images could not be obtained. The images used were acquired at low tide when possible in order to increase the accuracy of the classification study. Hierarchical unsupervised classification, coupled with filtering and contextual editing, was applied to each image. In addition, groundtruthing (with a handheld GARMIN GPS 76Cx, at an accuracy of ± 10 m) was also conducted at randomly chosen sampling points. GPS-tagged field photographs and videos were also taken during low tide conditions in order to relate image data to real features on the ground and therefore minimise errors in the classification.

RESULTS

Seagrass diversity and distribution in Singapore. — A total of 12 species of seagrass were recorded at 32 sites in Singapore (Table 1). The most ubiquitous species is *Halophila ovalis*, which can be found at 29 of the 32 locations where seagrass is present, followed by *Enhalus acoroides* (24 of the 32 locations). The species that occur least frequently are *Halodule pinifolia*, *Halophila decipiens*, and *Halophila minor*.

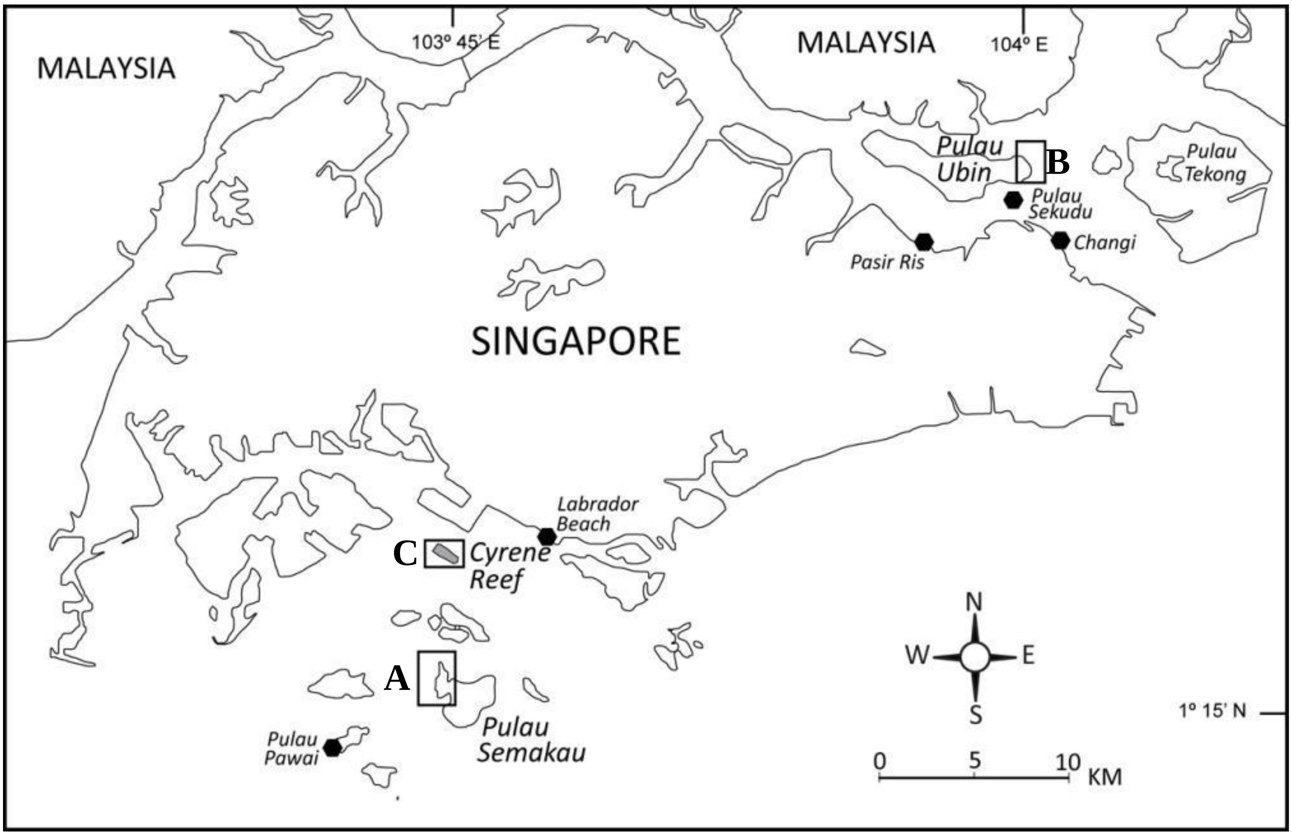

Fig. 1. The locations of Singapore’s three largest seagrass meadows: A, Pulau Semakau; B, Chek Jawa, Pulau Ubin; C, Cyrene Reef. The sites of five other substantial seagrass meadows are marked with a solid hexagon.

Table 1. The distribution of seagrass species by location. Data are compiled from records from the Singapore Botanic Gardens Herbarium (SING) and supplemented by field surveys conducted between 2006–2009. '*' refers to specimen/locations that only exist in Herbarium records; '+' denotes species observed during field observations (2007–2010); and '#' indicates field observations that have been corroborated with a lodged herbarium specimen. Species codes: CR = *Cymodocea rotundata*; CS = *Cymodocea serrulata*; HP = *Halodule pinifolia*; HU = *Halodule uninervis*; SI = *Syringodium isoetifolium*; EA = *Enhalus acoroides*; HB = *Halophila beccarii*; HD = *Halophila decipiens*; HM/HV = *Halophila minor*/*Halophila ovata* (*Halophila minor* and *Halophila ovata* are considered synonyms of each other and thus combined in this study [Short & Waycott, 2010; Short et al., 2010]); HO = *Halophila ovalis*; HS = *Halophila spinulosa*; TH = *Thalassia hemprichii*; P. = pulau (island); T. = terumbu (reef).

	FAMILY/SPECIES											
	Cymodoceaceae					Hydrocharitaceae						
LOCATIONS	CR	CS	HP	HU	SI	EA	HB	HD	HM/HV	HO	HS	TH
Western Johore Straits												
Tuas						+				+		
Lim Chu Kang Mangroves							#					
Sungei Buloh + Kranji						+	#					
Mandai							+					
P. Pergam						*		*	*	*	*	
Eastern Johore Straits												
Pasir Ris Park										#		
Changi				+		*		#		+	+	
Tanah Merah	+					+				+		
P. Ubin	#		*	#		#	#			#	#	#
P. Sekudu						+				#	+	
P. Tekong						+				+		
Beting Bronok										+		
Southern Mainland												
Labrador Beach						#				+		+
Belayer Creek										+		
East Coast Park				+		+				+		
Southern Offshore Islands												
P. Belakang Mati (Sentosa Is.)				+		+				#		
P. Tekukor										#		#
P. Sikajang Pelepah (Lazarus Is.)										+		+
P. Sikajang Bendera (St. John's Is.)										+		
P. Tembakul (Kusu Is.)						+				+		
P. Hantu						+				+		
P. Semakau		#		#	#	#		#		#		#
P. Jong										+		+
P. Sudong						+				+		
P. Pawai	#	#		#	+	#				#		#
P. Biola				#		#				#		#
P. Satumu (Raffles Lighthouse)						+				#		
Southern Patch Reefs												
T. Pandan (Cyrene Reef)	#	#		#	#	#		+		#		#
T. Pempang Laut					+	+				+		+
Beting Bemban Besar		+			+	+				+		+
T. Raya						+				+		
T. Semakau		+				+				+		

Of these, *Halodule pinifolia* and *Halophila minor*/*Halophila ovata* exist only in herbarium records, as there has been no positive identification of either species during field surveys. A new addition to Singapore's seagrass diversity was made when a specimen of *Halophila decipiens* was discovered off Pulau Semakau in 2007 (SING 2008-273).

There appears to be a north–south dichotomy in the distribution of some species, with *Halophila beccarii* and *Halophila spinulosa* restricted only to locations in the north, and *Cymodocea serrulata* being restricted only to offshore southern islands and reefs. The largest seagrass meadows in Singapore are those found at Pulau Semakau, Cyrene Reef, and Chek Jawa, although sizeable beds are also present at Changi, Pasir Ris, Pulau Sekudu, Labrador Beach, and Pulau Pawai (Fig. 1). The three locations with the highest number of species of seagrass are also Chek Jawa, Pulau Semakau, and Cyrene Reef (Table 1).

Extent of Singapore's three largest seagrass meadows. — The total extent of the three mapped seagrass meadows (Fig. 2) was approximately 33.7 ha, with the largest meadow found at Cyrene Reef (14 ha), followed by Pulau Semakau (13.7 ha) and Chek Jawa (6.5 ha).

Pulau Semakau has the largest continuous seagrass meadow in Singapore, measuring approximately 2 km in length along the intertidal on the western shore of the island (Fig. 2A). This meadow is predominantly *Enhalus acoroides*, interspersed with a mix of *Cymodocea serrulata*, *Syringodium isoetifolium*, and *Thalassia hemprichii*. Smaller patches of seagrass (mainly pioneering *Halophila ovalis*) are found elsewhere in the intertidal zone. No seagrass meadows on the reefs adjacent to Pulau Semakau were detected from the satellite images, but ground surveys showed there are some seagrass on these reefs (Table 1).

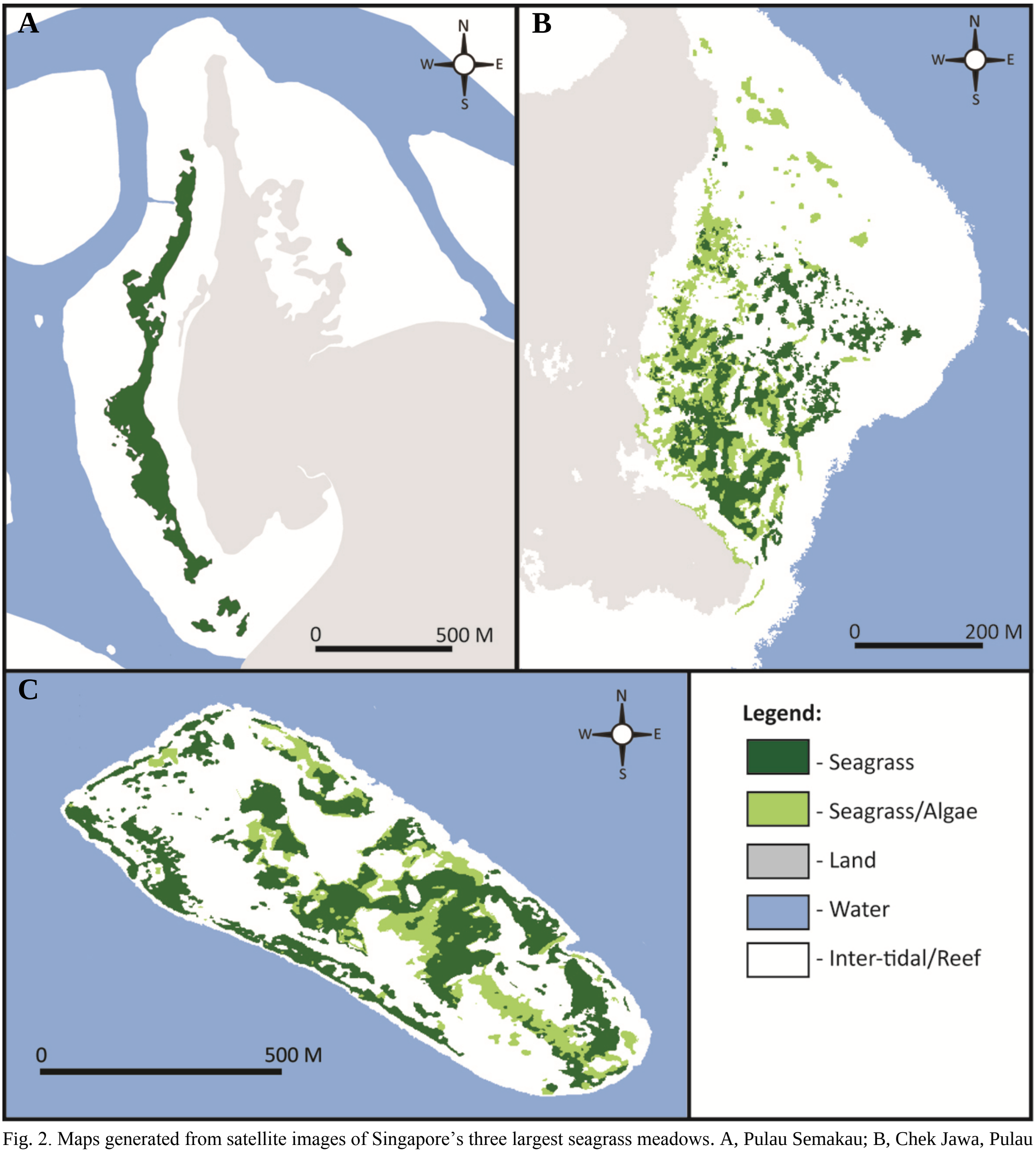

Fig. 2. Maps generated from satellite images of Singapore's three largest seagrass meadows. A, Pulau Semakau; B, Chek Jawa, Pulau Ubin; and C, Cyrene Reef. Please see Fig. 1 for their locations with respect to Singapore Island.

In comparison, the results indicate that seagrass cover at Chek Jawa is patchy with cover more dense in some areas (such as in the southern end) than others (Fig. 2B). However, groundtruthing indicated that the aboveground seagrass cover at Chek Jawa is actually quite homogeneous, but species composition varies, with the southern end dominated by *Cymodocea rotundata* and the rest of the meadow composed of a mix of *Halophila ovalis* and *Halodule uninervis*.

At 14 ha, Cyrene Reef is the largest seagrass meadow in Singapore (Fig. 2C). Seagrass cover at Cyrene Reef is mostly concentrated on the reef top in the centre of the reef, although seagrass is also found growing close to the reef edge in a coral rubble area. Similar to Chek Jawa, results indicate that the seagrass cover at Cyrene Reef is not continuous, but instead is comprised of a number of large patches. The seagrass meadow at Cyrene Reef is multi-specific, predominantly made up of *Enhalus acoroides*, *Cymodocea serrulata*, *Syringodium isoetifolium*, and *Thalassia hemprichii*. Other species found at Cyrene Reef are *Cymodocea rotundata*, *Halodule uninervis*, and *Halophila ovalis.*

DISCUSSION

Despite its limited coastal waters, Singapore's total seagrass species diversity is comparable to that of neighbouring countries such as Malaysia, Indonesia, and Thailand. However, while seagrasses occur on many sandy shores and mudflats in Singapore, the species richness at these sites tends to be low, usually comprising of *Enhalus acoroides* and *Halophila ovalis* (two of the most common species). There are only a few areas in Singapore where seagrasses form substantial and multi-specific meadows, the largest of which are Chek Jawa, Pulau Semakau, and Cyrene Reef.

It is interesting to note that two species, *Halodule pinifolia* and *Halophila minor*/*Halophila ovata*, only exist as herbarium specimens. Both these species were recorded as part of Singapore's seagrass flora in previous literature (Loo et al., 1996) but are conspicuously missing in recent field surveys. This absence may stem from the fact that there are some contentions regarding the legitimacy of both species. *Halophila minor* and *Halophila ovata* are both thought to be small-leaved variants belonging to the *Halophila ovalis* species complex, whereas *Halodule pinifolia* is thought to be the narrow-leaved version of *Halodule uninervis* (Waycott et al., 2004). Studies on the genetics of both these taxa have failed to lend support to *Halodule pinifolia* and *Halophila minor*/*Halophila ovata* being distinct species (Waycott et al., 2006; Lucas et al., 2012). In light of this evidence, it is possible that the herbarium specimens are actually wrongly identified. Unfortunately, an attempt to re-determine all of the specimens failed as some of the key identifying features of these species do not preserve well when dried.

The present study represents the first attempt at quantifying the extent of seagrass habitats in Singapore waters through remote sensing. As no previous areal estimates exist for seagrass habitats, this represents a baseline. Naturally, the total extent of the larger seagrass meadows in Singapore is small when compared to those of neighbouring countries (Green & Short, 2003), as there are only a few sites where seagrasses form substantial meadows. Yet, despite the lack of large meadows, there exists a diversity of seagrass habitat types. In tropical regions such as North-Eastern Australia, seagrass habitats are typically classified as estuarine, coastal, reef-associated or deep-water meadows (Carruthers et al., 2002), and three of these meadow types can be found in Singapore.

The seagrass meadows found in the waters to the north of Singapore Island tend to be estuarine and mangrove associated, whereas meadows found among the Southern Islands are reef associated and found on reef tops, such as Cyrene Reef, or intertidal/coastal meadows like Pulau Semakau. This is expected as there are large river catchments on the Malay Peninsula that drain into the northern straits between Singapore and Malaysia, such as the Johor River that discharges into the area between the eastern tip of Pulau Ubin and Pulau Tekong in the northeastern part of Singapore. On the other hand, the islands and reefs off the southern coast of Singapore are geologically distinct from the northern coast (Lu et al., 2005), with considerably less freshwater influence. This variety of seagrass habitat types should help support high biodiversity because while ecosystem functions of seagrass meadows generally remain the same, the different combinations of species composition, sediment type, and proximity to other marine habitats generally results in different meadow types supporting different suites of flora and fauna (Heck & Wetstone, 1977; Livingston, 1984; Lee et al., 2012a).

Each of the three seagrass meadows mapped presented a unique challenge for the remote sensing exercise. We encountered a sub-pixel effect (Doerffer et al., 1989) occurring for sites with smaller-leaved species such as *Halophila ovalis* and *Halodule uninervis*, which may be the cause for patchiness observed in the processed imagery. In such locations, the total leaf area of these small species within a 2×2 m^2 WorldView-2 pixel may be too sparse for detection. Instead, the net signal from a pixel will be dominated by the underlying sand/substrate. In the case of Chek Jawa, the issue of sub-pixel patchiness may lead to an underestimation of the actual extent of the meadow. Sub-pixel patchiness remains a challenge in remote sensing at varying spatial scales, particularly when oceanographic features are concerned (Lee et al., 2012b).

While Cyrene Reef and Pulau Semakau share a similar suite of species, seagrass cover at the two sites are different. Cyrene is a reef-associated meadow and it is not unusual for these meadow types to have micro-habitats such as sand mounds, sand bars, and coral rubble interspersed within the seagrass cover (Carruthers et al., 2002). Its location on a reef also influences the sediment composition present, with a large percentage of sand and coral rubble that the seagrass grows on. In contrast, Pulau Semakau is an intertidal seagrass meadow with a landward edge and is likely to have terrigenous and mangrove influences in its sediment mix, which appears conducive to the growth of both *Enhalus acoroides* and *Thalassia hemprichii* (Erftemeijer, 1994; Tanaka & Kayanne, 2007).

CONCLUSIONS

Twelve species of seagrass have been recorded in Singapore, half the number found in the Indo-Pacific (Ooi et al., 2011). However, two species, *Halodule pinifolia* and *Halophila minor*/*Halophila ovata*, have not been encountered during field surveys for many decades, casting doubt on their present status. We compiled a list of locations supporting seagrasses and the species found there (Table 1) which, together with the maps of the three largest seagrass meadows, provides a baseline for detecting change over time.

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