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Review

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Seagrass in Southeast Asia: a review of status and knowledge gaps, and a road map for conservation

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Abstract: Southeast Asia has the highest diversity of seagrass species and habitat types, but basic information on seagrass habitats is still lacking. This review examines the known distribution, extent, species diversity, and research and knowledge gaps of seagrasses in Southeast Asia by biogeographic region of the Marine Ecoregions of the World (MEOW). The extent of seagrass meadows in Southeast Asia is ~36,762.6 km^2 but this is likely an underestimate as some ecoregions were not well-represented and updated information was lacking. There is a paucity of information from the Western Coral Triangle Province, with no areal extent data available for the Indonesian regions of Kalimantan, Central and Southeast Sulawesi, the Maluku Islands, and West Papua. Regional research output has increased in the last two decades, with a trend towards more experimental, rather than descriptive research. However, there are knowledge gaps in socio-cultural-economic themed research, despite growing awareness of the importance of seagrass-human relationships in this region. Obstacles to advancing seagrass research, knowledge and conservation are rooted in either lack of expertise and training or the failure of effective management and policies. We propose a roadmap for seagrass conservation, with suggested solutions, including 1) encouraging collaboration between research institutions and scientists in the region to build capacity and share knowledge; 2) engaging with policymakers and governments to encourage science-based policies; 3) engaging with communities to raise awareness and foster stewardship of seagrass in the region.

Keywords: conservation challenges; developing states; marine ecoregion; research gaps.

Introduction

Southeast Asia is a biologically, culturally, and ethnically diverse region, made up of 14 countries, many of which are archipelagic states (Tangsubkul 1984). The region as a whole has seen a rapid population expansion of nearly sixfold between 1900 and 2000 (Jones 2013). The current population stands at approximately 622 million people, with most of the population concentrated in coastal capital cities (Figure 1). The region is also a global biodiversity hotspot, with high numbers of endemic species in both the marine and terrestrial environments (Sodhi et al. 2010, Tittensor et al. 2010). The cost of rapid population expansion and economic development in the region has resulted in devastating losses in terms of biodiversity on land (Sodhi et al. 2004), with similar impacts on marine biodiversity, although the true extent of this is still likely not fully realised, given the paucity of information from this region (Chou 2014).

Despite being a key component of marine ecosystems, seagrass meadows are a prime example of a habitat that is largely understudied and underdocumented in the Southeast Asian region (Waycott et al. 2009), with only 62 ISI cited seagrass-related publications between the 1980s and 2010 (Ooi et al. 2011a), most of which are on two specific sites in Northwest Luzon in the Philippines, and South Sulawesi in Indonesia. Much of the literature on seagrass in this region exists as grey literature, stemming from globally funded initiatives such as the UNEP-GEF South

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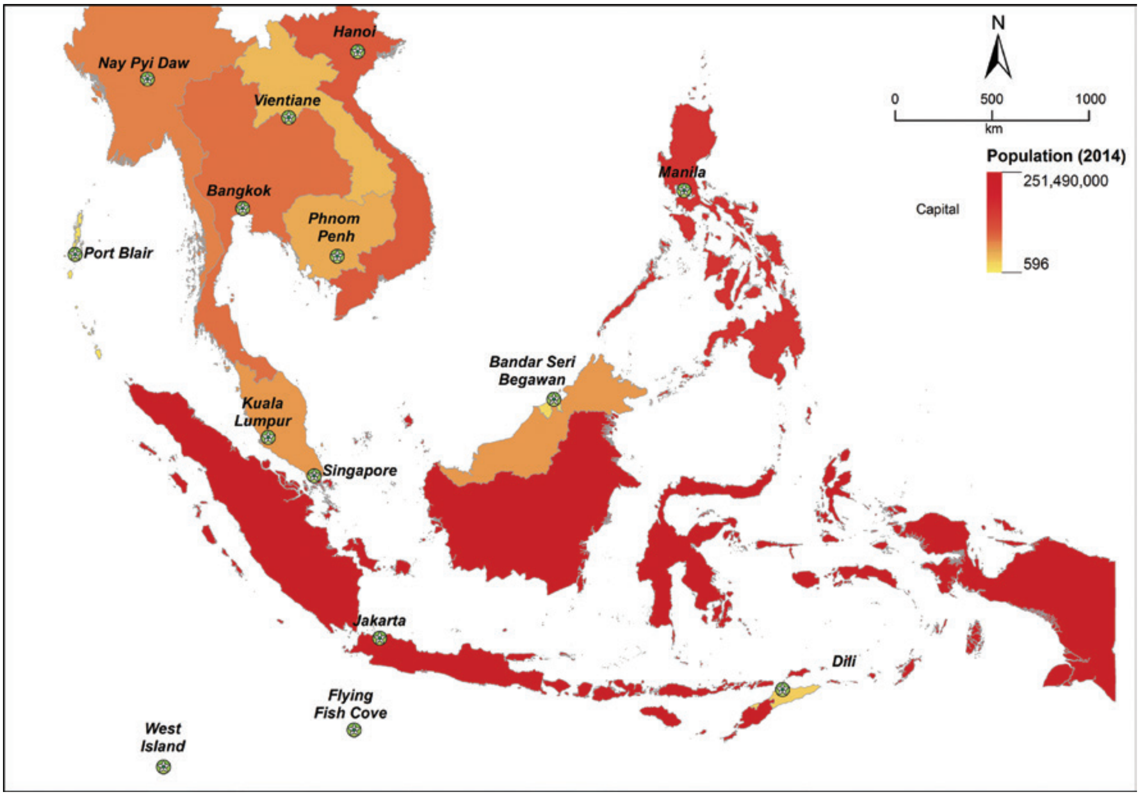

Figure 1: Total population by country in Southeast Asia. Population figures derived from www.worldatlas.com.

China Sea Project (UNEP 2008), yet these projects focus on specific areas, while excluding the wider Southeast Asian region, which is data depauperate. Seagrass meadows are widely recognised as offering a number of key ecosystem services, such as habitat formation, nutrient cycling, carbon sequestration, and food provisioning (William and Heck 2001, McGlathery et al. 2007, Fourqurean et al. 2012, Cullen-Unsworth and Unsworth 2013), with many coastal populations within Southeast Asia directly dependent on these habitats for a living (Unsworth and Cullen 2010). Seagrasses also continue to decline at a global rate of approximately 7% (Waycott et al. 2009), and the losses may be more acute in the Southeast Asian region due to the pressure from increasing coastal populations and developments, and the lack of data on seagrass resources. Perhaps just as important are the socio-economic-cultural links between seagrass meadows and coastal populations, which is only now coming to the attention of researchers (Unsworth and Cullen 2010).

The causes of seagrass loss in Southeast Asia have been documented in two other reviews (Fortes 1995, Kirkman and Kirkman 2002), and these threats, and their associated challenges, still remain relevant today. This review paper will instead focus on the current state of knowledge of seagrass in Southeast Asia, focusing on the the extent of seagrass within the diverse biogeographic regions of its marine environments. Based on the status review, we focus on the areal gaps in knowledge within Southeast Asia, followed by a more general thematic gap analysis. We also address the conservation and management challenges based on these gaps, and propose a broad roadmap for seagrass conservation and research in Southeast Asia, in order to develop the adaptive capacity of the coastal environment and its dependent human populations.

Status of seagrass in Southeast Asia

Seagrass distribution and extent by biogeographic region

There are six seagrass bioregions that encompass all the oceans of the world, across both tropical and temperate waters (Short et al. 2007). Southeast Asia lies within the

Indo-West Pacific bioregion (Bioregion 5), a vast region stretching from east Africa to the eastern Pacific Ocean, notable for being the largest and most biodiverse (24 species). However, Southeast Asia itself is potentially a distinct biogeographic province within the Indo-West Pacific, as indicated by the cluster analysis by Fortes (1988) for the seagrasses of the Indo-West Pacific. The Philippines and Brunei Darussalam were also shown to be slightly differentiated from other areas because of high seagrass species numbers in the former and low species numbers in the latter (Fortes 1988), which suggests that even finer-scale regions within Southeast Asia may exist, if based on updated distribution data.

In this review, we use the Marine Ecoregions of the World (MEOW) biogeographic scheme to provide the geographical context for seagrass distribution. The MEOW biogeographic scheme classifies all coastal and shelf areas of the world according to benthic and pelagic biota (Spalding et al. 2007), producing a nested system of 12 realms, 62 provinces, and 232 ecoregions. Based on this classification, the seas of Southeast Asia consist of seven provinces and 22 ecoregions (Figure 2), extending from the Bay of Bengal and the Andaman Sea in the west, to the Arafura Sea in the east. The provinces vary in size, with the largest being the Western Coral Triangle Province, which contains seven ecoregions. The Bay of Bengal Province and Sahul Shelf Province are only partly included in what we define as Southeast Asia in this review, which explains their relatively small size in Figure 2.

Species richness at the province level is highest in the Sunda Shelf and Western Coral Triangle (15 species). Within these provinces, species richness in the individual ecoregions ranges from 3 to 14 species (Table 1), but note that we excluded *Halophila gaudichaudii* and *Halophila tricostata* from our dataset because of locational uncertainty. Low species counts were found in the Cocos-Keeling/Christmas Island ecoregion (3 species) and the South China Sea Oceanic Islands ecoregion (4 species). Both ecoregions are fairly isolated, comprising atolls with lagoon seagrass meadows. Low species richness here likely reflects either a limited dispersal pathway between meadows in the greater Southeast Asian region and these remote sites, or a lack of suitable ecological drivers for the majority of species in these lagoons.

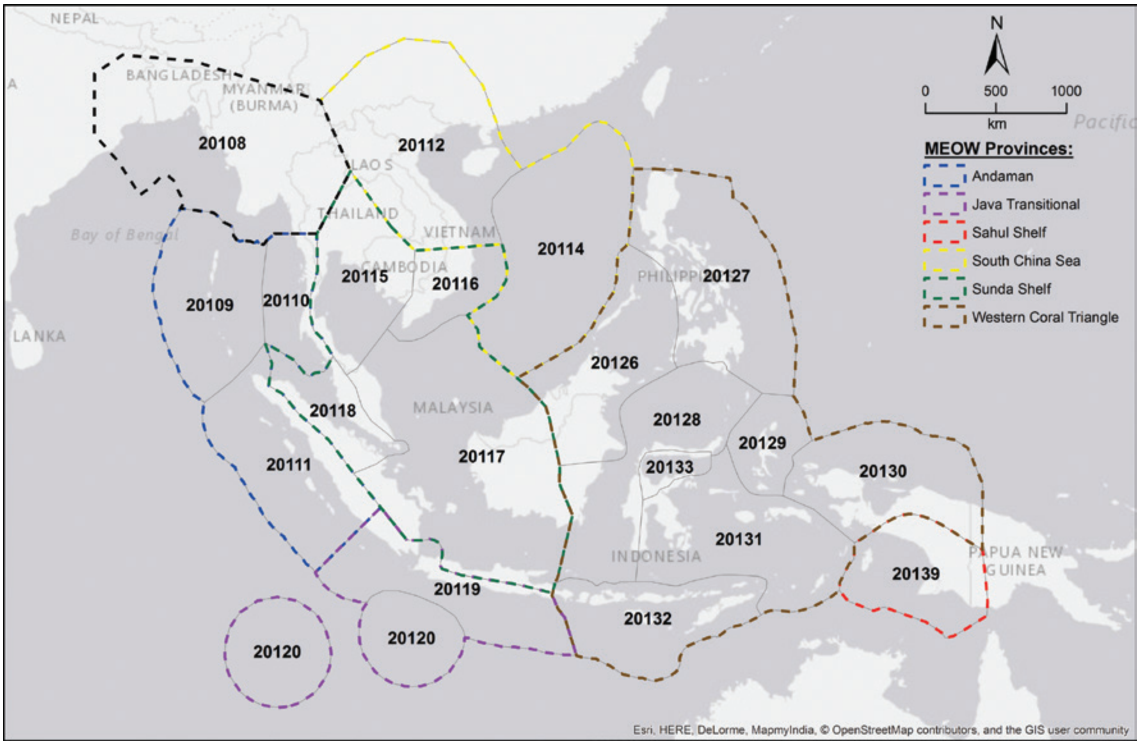

Figure 2: Marine provinces and ecoregions of Southeast Asia, based on Spalding et al. (2007).
Provinces are made out of ecoregions with the following codes: 20108 Northern Bay of Bengal; 20109 Andaman and Nicobar Islands; 20110 Andaman Sea Coral Coast; 20111 Western Sumatra; 20112 Gulf of Tonkin; 20114 South China Sea Oceanic Islands; 20115 Gulf of Thailand; 20116 Southern Viet Nam; 20117 Sunda Shelf/Java Sea; 20118 Malacca Strait; 20119 Southern Java; 20120 Cocos-Keeling/Christmas Island; 20126 Palawan/North Borneo; 20128 Sulawesi Sea/Makassar Strait; 20129 Halmahera; 20130 Papua; 20131 Banda Sea; 20132 Lesser Sunda; 20133 Northeast Sulawesi; 20139 Arafura Sea.

Table 1: Number of seagrass species and extent of known meadows in marine bioregions of Southeast Asia.

Province/ecoregion	No. of species/province	No. of species/ecoregion	Seagrass area (km²)
Bay of Bengal	**10**		
Northern Bay of Bengal (20108)		10	0.7
Andaman	**13**		
Andaman and Nicobar Islands (20109)		9	8.3
Andaman Sea Coral Coast (20110)		11	58.2
Western Sumatera (20111)		9	ND
South China Sea	**8**		
Gulf of Tonkin (20112)		5	36.9
South China Sea Oceanic Islands (20114)		4	ND
Sunda Shelf	**15**		
Gulf of Thailand (20115)		12	519.4
Southern Viet Nam (20116)		12	19.9
Sunda Shelf/Java Sea (20117)		13	5.2
Malacca Strait (20118)		14	21.7
Java Transitional	**12**		
Southern Java (20119)		12	134.4
Cocos-Keeling/Christmas Island (20120)		3	26.0
Western Coral Triangle	**15**		
Palawan/North Borneo (20126)		12	20,115.3
Eastern Philippines (20127)		11	7158.9
Sulawesi Sea/Makassar Strait (20128)		13	0.9
Halmahera (20129)		5	402.6
Papua (20130)		8	5.3
Banda Sea (20131)		12	8246.2
Lesser Sunda (20132)		13	2.7
Northeast Sulawesi (20133)		5	ND
Sahul Shelf	**7**		
Arafura Sea (20139)		7	ND

Provinces are in bold; ecoregions are in italics. ND denotes the absence of data. In assessing number of species, *Halophila gaudichaudii* and *H. tricostata* were excluded from this dataset because of locational uncertainty within ecoregions. Seagrass area values were available for very few sites in comparison to what we know about seagrass extent in the region, and should be regarded as underestimates.

In contrast, the Malacca Strait emerges as an ecoregion of special interest in terms of species richness. It is amongst the smallest of the ecoregions but supports 14 seagrass species (Table 1). This narrow strait, measuring 926 km in length, is one of the busiest shipping lanes in the world because it connects the Indian Ocean to the South China Sea (Mokhzani 2004, Ibrahim and Nazery 2007). This may partly explain its high seagrass species richness, as in the case of marine fish (Carpenter and Springer 2005). In an analysis of global shore fish biodiversity, the location of the strait in an area of overlap between Indian and Pacific ocean fauna was suggested as a likely explanation for high species richness (Carpenter and Springer 2005). In terms of gene flow, this ecoregion is recognised as the Indo-Pacific Barrier (Bowen et al. 2016), the equivalent of a marine Wallace line that separates populations of marine fauna on either side of the strait through shifts in sea level during periods of glaciation. This insight is useful in guiding the selection of sampling locations for seagrass phylogeographic studies that address questions about biodiversity distributions in Southeast Asia, and specifically in testing hypotheses about Southeast Asia as a centre of overlap, refuge, accumulation or centre-of-origin for seagrass, such as those suggested by Mukai (1993) and Nguyen et al. (2013), Nguyen et al. (2014). However, we see the need to draw attention to the fact that development in the Malacca Strait due to shipping, port construction, and land reclamation are likely factors that will determine how rapidly seagrasses, as well as other marine ecosystems, are likely to change in the near future (Mokhzani 2004, Ibrahim and Nazery 2007).

The most widespread species in Southeast Asia is *Thalassia hemprichii*, which had distribution records in all ecoregions, even in locations as remote as the South China Sea Oceanic Islands. *Cymodocea serrulata* and *Cymodocea rotundata* are common species as well, occurring in all ecoregions except for the South China Sea Oceanic Islands and the Cocos-Keeling/Christmas Islands. Species that were unique to one ecoregion were *Halophila sulawesii* (Kuo 2007), with only one record in Samalona Island of the Spermonde archipelago (see also: Taxonomic Highlights, below), and *Zostera japonica* in the Gulf of Tonkin (Luong et al. 2012). *Halophila major* and *Halophila ovata* are also limited to single ecoregions in the Northern Bay of Bengal, and the Andaman and Nicobar Islands, but this may be because these forms are taxonomically difficult to identify (addressed in Taxonomic Highlights below), although recent progress has been made in molecular approaches (Nguyen et al. 2013, 2014).

The extent of seagrass meadows in Southeast Asia is currently 36,762.6 km^2 (Table 1). The largest areas are in the Palawan/North Borneo (20,115 km^2), Eastern Philippines (7159 km^2) and Banda Sea (8246.2 km^2) ecoregions, all of which are part of the Western Coral Triangle Province. Not all ecoregions are as well-represented in terms of seagrass meadow estimates. The South China Sea Oceanic Islands, Western Sumatera, Northeast Sulawesi, and the Arafura Sea ecoregions, for example, have obvious information gaps. These will be further highlighted in Section "Areal gaps in knowledge and information".

Seagrass distribution and extent by country

Recent updates now show Southeast Asia to have 21 seagrass species in nine genera and four families, which makes up 29% of the world's seagrass species (Table 2). Seagrass species diversity is highest in the Philippines (19 species), and lowest in Brunei (7 species), which is the country with the most recent additions to its species list (Lamit et al. 2017).

The nation states of Southeast Asia have a collective coastline of more than 100,000 km that encompass at least 675,824 km^2 of territorial seas (Flanders Marine Institute

Table 2: Seagrass species distribution in Southeast Asia by country/territory.$^+$

Family and species	BN	ID	CM	MM	MY	PH	SG	TH	VN	AN$^+$
Family Hydrocharitaceae										
Enhalus acoroides (L. f.) Royle	•	•	•	•	•	•	•	•	•	•
Thalassia hemprichii (Ehrenb.) Aschers. *in* Petermann	•	•	•	•	•	•	•	•	•	•
Halophila beccarii Aschers.	•	•	•	•	•	•	•	•	•	
Halophila decipiens Ostenfeld		•	•	•	•	•	•	•	•	
Halophila gaudichaudii J. Kuo						•				
Halophila major (Zoll.) Miq.		•		•	•	•		•	•	
Halophila minor (Zoll.) den Hartog		•	•	•	•	•	•	•	•	
Halophila ovalis (R. Br.) Hook. f.	•	•	•	•	•	•	•	•	•	•
Halophila ovata Gaudich. and in Freycinet						•				•
Halophila spinulosa (R. Br.) Aschers.	•	•		•	•	•	•			
Halophila sulawesii J. Kuo		•								
Halophila sp. 1						•				
Halophila sp. 2 (*Halophila tricostata* Greenway)					•	•				
Family Cymodoceaceae										
Cymodocea rotundata Ehrenb. *et* Hempr. *ex* Aschers.	•	•	•	•	•	•	•	•	•	•
Cymodocea serrulata (R. Br.) Aschers. *et* Magnus		•	•	•	•	•	•	•	•	•
Halodule pinifolia (Miki) den Hartog	•	•	•	•	•	•	•	•	•	•
Halodule uninervis (Forssk.) Aschers.		•	•	•	•	•	•	•	•	•
Syringodium isoetifolium (Aschers.) Dandy		•	•	•	•	•	•	•	•	•
Thalassodendron ciliatum (Forssk.) den Hartog		•			•	•			•	
Family Ruppiaceae										
Ruppia maritima L.		•	•		•	•		•		
Family Zosteraceae										
Zostera japonica Aschers. *et* Graebn.									•	
Total no. of species	7	16	12	13	16	19	12	13	14	9

Country codes and references used to compile this list as follows: BN, Brunei (Fortes 1988, Lamit et al. 2017); ID, Indonesia (Kuo 2007, Wawan 2011, Tuntiprapas et al. 2015); CM, Cambodia (UNEP 2008, Vibol et al. 2010); MM, Myanmar (Novak et al. 2009, Soe-Htun et al. 2009, Nguyen et al. 2014, BOBLME 2015); MY, Malaysia (Japar Sidik and Muta Harah 2011, Nguyen et al. 2014); PH, Philippines (Fortes 1989, Waycott et al. 2002, Fortes 2013, Kim et al. 2017); SG, Singapore (Yaakub et al. 2013); TH, Thailand (Nguyen et al. 2014, Tuntiprapas et al. 2015); VN, Viet Nam (Nguyen et al. 2013, 2014); AN, Andaman and Nicobar Islands (Jagtap et al. 2003, Tangaradjou et al. 2010), the "+" denoting this is a union territory of India.

2016). The Philippines has the largest seagrass extent, with seagrass meadows constituting at least 24% of its territorial waters – the largest proportion in the region (Table 3). In contrast, Myanmar and Malaysia have the lowest proportion of known seagrass areas relative to the size of their territorial seas (≤0.02%), while Timor-Leste has yet to produce areal estimates of seagrass meadows. This provides a guide to which countries in particular require greater capacity-building in developing spatial databases for seagrass.

Taxonomic notes

The seagrass species list of Southeast Asia (Table 2) shows 21 species, but some of these are still considered taxonomically uncertain. The genus with the greatest number of unvalidated species is *Halophila*. This genus has high taxonomic diversity, but its constituent forms appear to have overlapping leaf morphologies that have made validation problematic. The plasticity of this species in response to different substratum, salinity, and light regimes has been demonstrated (Young and Kirkman 1975, Benjamin et al. 1999, Japar Sidik et al. 2010), and is the main reason for taxonomic uncertainty on the basis of morphological traits alone. In Table 2, we show *Halophila* to consist of nine recognised species and two undescribed species, *Halophila* sp. 1 (the Philippines) and *Halophila* sp. 2 (Malaysia and Philippines). Amongst those we list as recognised species, however, we acknowledge that *H. major, H. gaudichaudii*, *H. minor*, and *H. ovata*, which are regarded as being part of the *H. ovalis* complex (Waycott et al. 2004), which may now include *H. sulawesii*, are undergoing taxonomic scrutiny in this region, which we briefly summarise below.

In Southeast Asia, *Halophila major* has been studied in greater detail than other species in its genus, through a combination of morphological and molecular traits. As a result, it has become a recent entry into the species records of Indonesia (Tuntiprapas et al. 2015), Thailand (Tuntiprapas et al. 2015), Malaysia (Japar Sidik *pers. obs;* see Figure 3), Myanmar (Nguyen et al. 2014), Viet Nam (Nguyen et al. 2013, 2014), and the Philippines (Kim et al. 2017). *Halophila minor* and *Halophila ovata* were treated as synonyms for the seagrass flora of Singapore (Yaakub et al. 2013) despite being recognised as two distinct species by Kuo (2000). However, *H. ovata* was subsequently considered an illegitimate name and proposed as *Halophila gaudichaudii* by Kuo et al. (2006). As a result, all these

Table 3: Extent of known seagrass areas in Southeast Asia, arranged according to seagrass area size for each country.[a]

Country/Territory+	Coastline extent (km)	Seagrass area (km^2)	Proportion of territorial seas with seagrass (%)[a]	Source
Philippines	36,289	27,262.2	24.24	World Bank 2005
Indonesia	80,791	8812.9	3.06	Neinhuis et al. 1989, de Iongh et al. 1995, Douven et al. 2003, Arifin 2004, Kuriandewa and Supriyadi 2006, UNEP 2008, Kamal et al. 2010, Unsworth 2010, van Katwijk et al. 2011, Torres-Pulliza et al. 2013, Patty 2016, Kawaroe et al. 2016, Fitrian et al. 2017, Mintje 2017
Cambodia	435	324.9	6.19	UNEP 2008
Thailand	2583	148.5	0.29	Poovachiranon et al. 2006, UNEP 2008
Viet Nam	3200	157.4	0.25	Luong et al. 2012
Cocos-Keeling/Christmas Island+	26	26.0	–	Hobbs et al. 2007
Malaysia	4800	16.3	0.02	Japar Sidik and Muta Harah 2003, Jaaman et al. 2011, Anscelly 2014, Ooi et al. 2014, Rajamani and Marsh 2015, Hossain et al. 2015a,b, Japar Sidik and Muta Harah 2011
Andaman and Nicobar+	1962	8.3	–	Tangaradjou et al. 2010
Myanmar	3060	4.3	0.01	BOBLME 2015
Brunei	161	1.5	0.05	Lamit et al. 2017
Singapore	193	0.3	0.04	Yaakub et al. 2013
Timor-Leste	706	Unknown	Unknown	–
Total	117,763	36,762.6		

Proportion of territorial seas with seagrass was calculated for each country or territory based on territorial sea area values obtained from Flanders Marine Institute (2016). +Cocos Keeling/Christmas Island and Andaman and Nicobar Islands are territories of Australia and India respectively. [a]Territorial seas are defined as areas of water "enclosed within the maritime delimitations of a coastal state extending 12 nautical miles seawards from the baselines" (Flanders Marine Institute 2016). Estimates were not made for territories. Seagrass area values were available for very few sites in comparison to what we know about seagrass extent in the region, and should be regarded as underestimates.

Figure 3: *Halophila major* from Tanjung Adang Laut, Sungai Pulai estuary, Johor (refer also to Nguyen et al. 2014 for morphological and genetic identification of the species).
Photo credit: © Muta Harah.

Figure 4: *Halophila* sp. 2 collected in 1997 at a mangrove area of Teluk Sepinong, Sandakan, Sabah, Malaysia.
Photo credit: © Japar Sidik.

confounding species, i.e. *H. minor, H. ovata* and *H. gaudichaudii* are present in the species records of this region, and are reported as such in this review on the grounds of maintaining the transparency of these species lists until a taxonomic consensus is reached. We note, however, that *H. major* appeared in the records of Viet Nam (Southern Viet Nam ecoregion) and Myanmar (Northern Bay of Bengal ecoregion); *H. gaudichaudii* in the records of the Philippines (ecoregion undetermined); and *H. ovata* in the Andaman and Nicobar Islands, and the Philippines (ecoregion undetermined).

In Table 2, there are two unidentified *Halophila* species, i.e. *Halophila* sp. 1 from Malita, Davao del Sur, the Philippines (Fortes 2013) and *Halophila* sp. 2, from a mangrove area of Teluk Sepinong, Sandakan, Sabah, Malaysia (Japar Sidik and Muta Harah 2011). *Halophila* sp. 1 needs further verification. However, *Halophila* sp. 2 (Figure 4), was also reported as an uinidentified *Halophila* sp. nov., collected off Molleangan Island, near Banggi Island, Sabah (Rajamani and Marsh 2015), which has recently been described and identified as *Halophila tricostata* using molecular ITS sequence data in the Philippines (Calumpong et al. 2010, Tiongson 2012). *Halophila tricostata* is considered endemic to the east coast of Australia (Greenway 1979) and its presence in the species records of Southeast Asia indicates its potential for long distance dispersal from the Great Barrier Reef of Australia to the Palawan/North Borneo ecoregion.

The genus *Halodule* is another taxon that has been a source of uncertainty and confusion in species identification because of overlapping morphological characters (leaf width, leaf length dimensions) and species separation through their leaf tips (Phillips 1967, den Hartog 1970, Japar Sidik et al. 1999). *Halodule pinifolia* is considered to be the narrow-leaved form of *Halodule uninervis* (Waycott et al. 2004), but these have been shown through genetic analysis on samples in the Philippines to be separate species that have morphological variations in leaf width because of site-specific differences, density and exposure (Wagey and Calumpong 2013). Thus, we have maintained them as different species in Table 2.

Knowledge gaps

Areal gaps in knowledge and information

Information on seagrass in Southeast Asia is geographically unbalanced, with hotspots and coldspots of research effort. Within hotspots, the level of information itself is variable, with some providing reports of species presence, while others provide both species presence and estimates of meadow size. Estimates of meadow size are rarely reported because of the logistical challenges in mapping seagrass meadows. It has only been in recent years that areal estimates for seagrass meadows have begun to emerge more rapidly as a result of advancements in remote sensing technology and well-funded regional projects such as the UNEP/GEF South China Sea Project (UNEP 2008), the Bay of Bengal Large Marine Ecosystem Project (BOBLME 2015), and the JSPS-Asian CORE Project. We consider meadow size data to be particularly critical for moving seagrass conservation and management forward in the region because these provide baselines for understanding ecosystem trajectories, either under natural conditions or in response to environmental change over the long-term, as in the case of the global analysis of seagrass trajectories by Waycott et al. 2009. In this review, information gaps by geographic areas are visualised by plotting locations where data on species presence, meadow size, or both, are available in the region (Figure 5).

There is quite an even spread of sampling sites and a high level of information (species presence and seagrass areal extent) in the Gulf of Tonkin, the Gulf of Thailand, the Eastern Philippines, Lesser Sunda and the continental part of the Andaman Sea Coral Coast ecoregion (see solid points in Figure 5).

Ecoregions that potentially have seagrass habitats but which are data depauperate include:

1. The South China Sea Oceanic Islands, with merely one data point in the Layang-Layang atoll and no meadow area estimates;
2. The Sulawesi Sea/Makassar Strait, with most of the data points clustered on the southwestern and north-eastern coastline of Sulawesi, with no meadow area estimates;
3. The Sunda Shelf/Java Sea, especially on the islands of Borneo and Sumatera;
4. The Arafura Sea, which has just one data point, in the Aru group of islands.

Accessibility to seagrass sites influences the distribution of data points in the region, to a certain extent. Some sites are inaccessible to researchers because they are remote or are under territorial dispute. The South China Sea Oceanic Islands, which include the Spratly Islands, have both characteristics: they lie right in the centre of the South China Sea and have been the subject of multiple overlapping maritime claims by the Philippines, Malaysia, Viet Nam, Brunei, Taiwan and the People's Republic of China for more than 50 years. Because they are physically isolated, these sites are natural laboratories for testing ideas about allopatric differentiation in seagrass and seagrass-associated species, and to elucidate seagrass dispersal routes in the region. To take the example of fish larvae in the Spratly Islands, larval drift time and vector current charts indicate that the western Philippines, Taiwan, south-eastern China, Brunei, and Malaysia are direct sink habitats for coral reef fish from the Spratlys (McManus

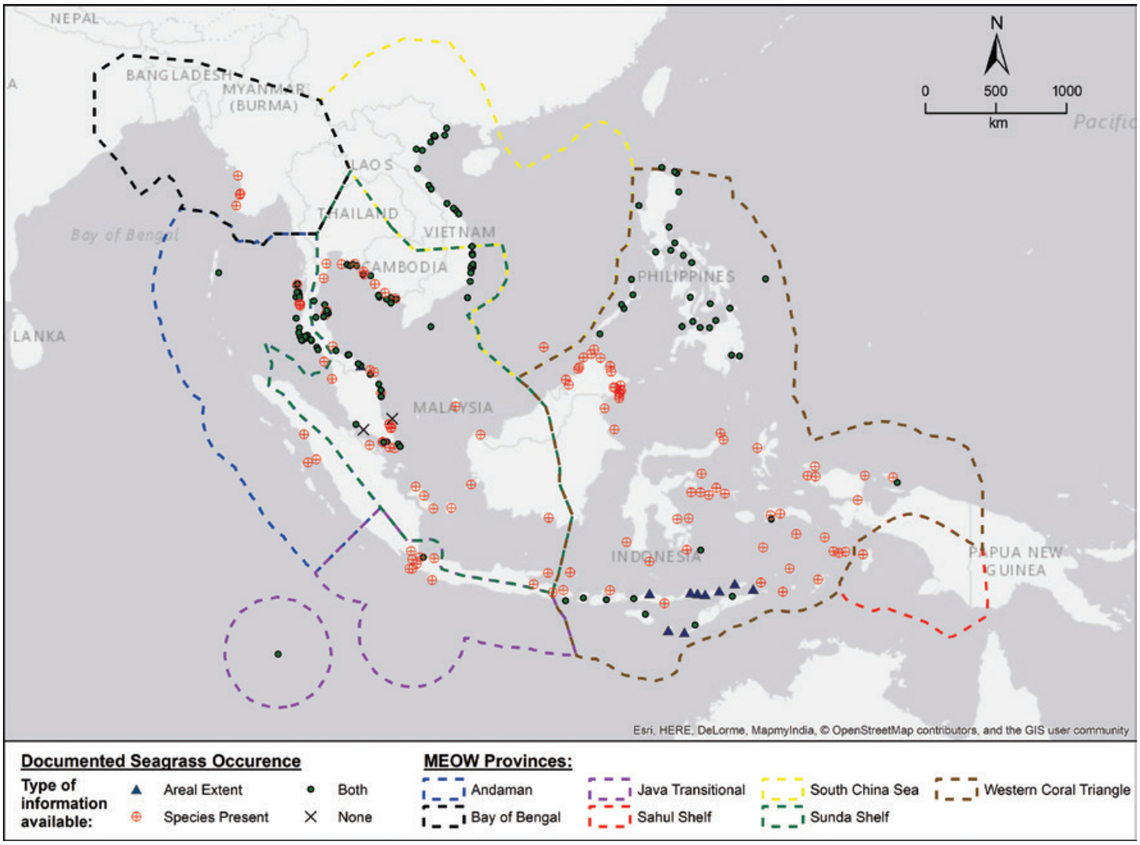

Figure 5: Level of seagrass information available within the Southeast Asian region.

2017). Long-distance dispersal in seagrasses has also been shown to be possible through seeds, fruits, viviparous seedlings and vegetative fragments, all of which have the capacity to move over hundreds of kilometers in distance (Kendrick et al. 2012). However, if seagrass scientists in the region hope to fill in this data gap, rapid action is necessary because of the amount of recent island-building in this ecoregion as a result of intense territorial claims (Southerland 2016). Island-building often involves sand-dredging and land reclamation on shallow coral reefs and in lagoons. To date, two-thirds of currently occupied atolls in the Spratlys have been shown to have proportionally less reef extent than unoccupied atolls, implying the detrimental effects of island-building on reef systems (Asner et al. 2017). Along with these reefs, seagrasses may also be equally damaged before being recorded and studied for science.

Google Earth images of the the Sulawesi Sea/Makassar Strait ecoregion show the presence of soft substrate coastlines, large estuaries, and outlying islands which are often associated with seagrass. Seagrasses appear to be widespread in this ecoregion, and the area of Derawan, east Kalimantan, in particular has been the subject of study (McKinnon et al. 1996, van der Zon 2010). However, the available sources mentioned seagrass in the area in a broad sense, without giving details of locations, full species list, or meadow extent. Similarly, the Sunda Shelf/Java Sea ecoregion has sparse datasets on the Malaysian side of Borneo despite anecdotal evidence for large areas of seagrass along those coastlines (Japar Sidik pers. obs.).

An observation that came up in this effort to review updated seagrass species and meadow information was that these were often categorised according to countries. This is certainly useful from a national point of view, but for seagrass science to be cohesive at the regional level, we need to ensure that information about species and meadow estimates are both sea-specific and country-specific. In this review, we used MEOW bioregions for this purpose. However, other biogeographic schemes may be just as useful, and we regard the use of bioregions as a starting point for scientists in the region to discuss data and information needs when collaborating on regional-scale studies.

Thematic gaps in knowledge and information

Seagrass research in Southeast Asia is increasing based on the number of research papers that have been produced in the last decade (Ooi et al. 2011a), and an update of the number of research articles, reports and studies that have been reported in the region has shown a steady increase in research output decade by decade for most countries (Figure 6). However, there are still noticeable gaps in knowledge in Cambodia, and Myanmar, as well as places like East Timor, Brunei, and the Cocos (Keeling) Islands. There is also an increase in the number of research papers, reports, and theses published by authors originating from or based in the country or region itself, which indicates an increase in research interest and capacity of local scientists. There has been an increase in the number of national

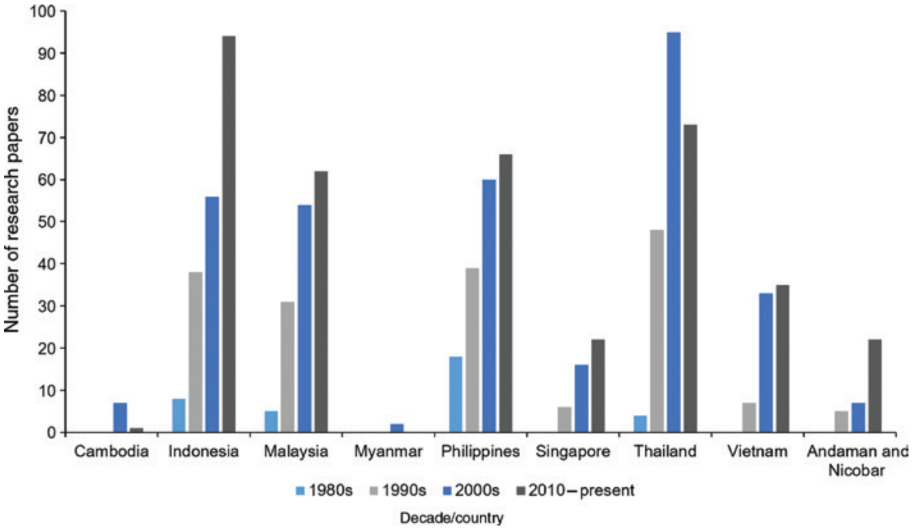

Figure 6: Research output per decade by country/territory.
Numbers based on searches on Web of Science and updated from Ooi et al. (2011a).

or regional journals being made available online, which has increased the visibility of the research being published, along with academic sharing and networking sites, such as ResearchGate™ which allows researchers with a verified profile to share their research output – both in journals as well as in other forms, such as reports, posters, conference proceedings, book chapters, etc. – to be shared publicly and directly with the platform's audience.

Taxonomic research continues to be a mainstay of the research efforts in this region, with new species – particularly in the *Halophila ovalis* species complex (Waycott et al. 2004) – being described (see Kuo 2007, Japar Sidik and Muta Harah 2011, Fortes 2013). However, there is an obvious need for traditional morphological seagrass taxonomy to embrace new methods in the field. There is currently already a Global Initiative to Barcode Seagrass (GIBS) based at the State Herbarium of South Australia and the University of Adelaide (GIBS 2018), and more participation from researchers in the Southeast Asian region may be beneficial for the advancement of seagrass taxonomy.

There is an increasing trend of research output for the region as a whole (Ooi et al. 2011a; Figure 6), and there are some distinct trends in the intensity of work within each thematic research area across the decades (Figure 7). There was a surge in the number of seagrass ecology and environment related research from the 1990s onwards, and this is by far the most productive research area in terms of output. There has also been a progression in this field moving away from purely descriptive to more experimental studies examining interactions and cumulative stressors and anthropogenic impacts of the major causes of seagrass decline such as sedimentation (Cabaço and Santos 2007, Manzanera et al. 2011, Ooi et al. 2011b, Han et al. 2012), water quality declines and light reduction (Bite et al. 2007, Leoni et al. 2008, Baden et al. 2010, Collier et al. 2011, Yaakub et al. 2014a), changes in temperature (Campbell et al. 2006, Collier and Waycott 2014, Gao et al. 2017), and competition with macroalgae (Davis and Fourqurean 2001, Taplin et al. 2005, Martinez-Luscher and Holmer 2010, Holmer et al. 2011).

New research themes also emerged in the 1990s concerning conservation and management (e.g. Fortes 1991, Kirkman and Kirkman 2002, Unsworth and Cullen 2010), and connectivity of seagrass habitats (e.g. Fortes 1988, Vermaat et al. 2004), likely in response to the trend of habitat loss from the rapid population expansion across Southeast Asia between the mid-90s and the present. There were also some new research areas – such as genetics (e.g. Matsuki et al. 2013, Nakajima et al. 2014, Arriesgado et al. 2015, Hernawan et al. 2017) and blue carbon (e.g. Miyajima et al. 2015, Alongi et al. 2016, Rozaimi et al. 2017) – that have increased in intensity, advancements, and improvements in protocols and methodology. More traditional research areas, such as mapping of areal extent of seagrass habitats, also received a boost in research output with improvements in remote sensing technology, and accessibility of satellite imagery. Continued interest in this field and expansion of research into more remote areas can help improve and continue to address information gaps in areal extent of seagrass meadows in the region, and also start to expand into examining seasonal variation and decline.

Despite the continued increase in research, it is plain to see that a lot of work still needs to be carried out in order to address the gaps in knowledge and information.

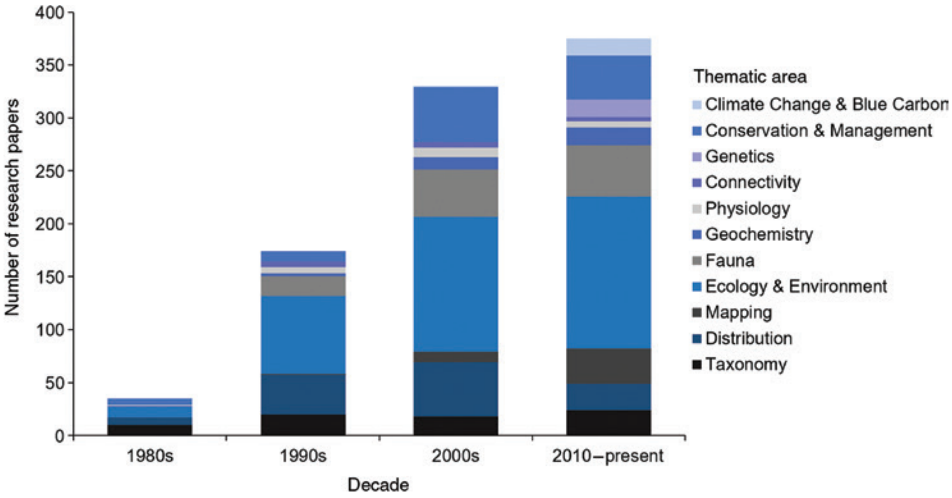

Figure 7: Research output for the Southeast Asian region by thematic area presented as decadal totals.

For example, there is virtually no social science research examining the social, cultural and economic aspects of human-seagrass interactions, and there is research emerging that points to important relationships between coastal populations and seagrass beds (Cullen-Unsworth et al. 2014). Furthermore, while the significance of seagrass fishery activity has been acknowledged globally (Nordlund et al. 2017), the lack of information on seagrass fishery resources and the flow-on benefits from ecosystem services it provides in the Southeast Asian region is a data gap that needs to be addressed (Unsworth et al. 2009). In Table 4, we suggest the direction for existing and new thematic research areas, as well as potential areas for regional research cooperation.

Paving the way: key challenges for the next decade

There have been previous articles and reviews on challenges for seagrass conservation in Southeast Asia, and while we do not wish to revisit them, the obstacles to the effective management and conservation of seagrass habitats must be addressed. If the experiences of coral reef and mangrove habitats are any indication, the past half century has taught us that the future of seagrass meadows in SE Asia is bleak, their degradation is expected to continue, despite greater local and region-wide conservation efforts and the promises of programs and projects being implemented and planned. Fortes (2013) addressed some key challenges for seagrass habitats in the context of the Philippines, but these concepts can be extrapolated and are widely applicable to the Southeast Asian region as a whole. We have summarised the six key challenges that are hampering efforts towards the successful management of seagrass habitats in the region in Table 5.

The first three challenges are rooted around the central problem of lack of knowledge, expertise, and information. Expertise in seagrass research and information on tropical seagrass habitats in the region was built on collaborations and partnerships with research partners from outside the region. Actual capacity building and training of researchers in the region seemed to be concentrated in some institutions, with little to no information sharing beyond those institutions (Table 5; Challenge #1). Where seagrass research was carried out by researchers outside the centers of knowledge, the work tends to be highly descriptive, which is likely fuelled by the lack of training, expertise, and resources (Table 5; Challenge #2). This lack of access to information and training, especially in basic methods, then exacerbates the problem of lack of basic knowledge of seagrass meadows in Southeast Asia (Table 5; Challenge #3), which results in a paucity of basic information such as spatial extent, species composition, and cover. To overcome these challenges requires a concerted and multi-pronged approach, and must come from researchers who are based in Southeast Asia themselves. Forming a network of scientists working in the region (even informally) builds a collaborative and supportive research and knowledge sharing network. Training workshops for young researchers and inter-institution collaboration and exchanges should be encouraged. Knowledge sharing can also avoid duplication of work and sharing of resources and equipment, and the institutional diversity could also put researchers in a better and more competitive position when it comes to funding opportunities.

The next three challenges are related to policy-making, and management of natural resources. While management efforts have been initiated at various sites across the region, these have largely focused on remedial or curative measures, and do not address the root problems (Table 5; Challenge #4). The causes of seagrass decline in Southeast Asia are well documented, and many of these are due to anthropogenic impacts related to coastal development. These impacts need to be addressed in order to stem further deterioriation of seagrass meadows across the region. Although attempts are occasionally made to undertake seagrass relocation and restoration, these are often not the most cost-effective solution as success rates are quite low despite a large input of effort and funds (van Katwijk et al. 2015). These ineffective solutions are also often compounded by the lack of effective linkages between science, government, and private sectors, leading to poor management and conservation actions taken. There is currently a big gap or disconnect between seagrass science, policy, and practice (Fortes 2018).

In turn, these management and conservation actions, or environmental laws are not always adequately enforced or implemented (Table 5; Challenge #5). It is especially difficult to slow down coastal development in the developing world, and even more challenging to justify conservation of natural habitats over economic growth. The prioritisation of economic growth means that environmental laws are not always put in place, with no proper safeguards against habitat degradation and destruction. Where environmental laws exists, they are not always effectively enforced as enforcement agents sometimes lack sufficient resources or authority to carry out their duties. Designation of marine parks is also often inadequate, with fishing, aquaculture, or other anthropogenic activities that impact

Table 4: Suggestions for future direction and potential regional cooperation in the different thematic areas.

Thematic research area	Future direction/expansion	Potential for regional cooperation?
Climate change/blue carbon	Address knowledge gaps on carbon storage potential of seagrass meadows in SE Asia. Economic and finance of blue carbon, and challenges in the SE Asian context Exploratory climate change scenarios for seagrass habitats and increasing resilience to effects of climate change	Yes. Many sites required for a complete picture of blue carbon storage potential in SE Asia. Both blue carbon and climate change research require concerted effort at wider scales
Conservation and management and ecology and environment	Research into more effective marine policy and integrated coastal zone management Review of current marine protected areas and reserves to include more seagrass habitats, and science-based zoning plans. Development of decision support tools for natural resource managers. Data collection on environmental and water quality parameters to understand changes at a regional scale	Yes. Using existing platforms such as the ASEAN Working Group on Coastal and Marine Environments (AWGCME) can help coordinate management efforts at the regional scale. Region-wide monitoring programs to increase rate of data collection across regions
Genetics	Increase population genetics studies to better understand connectivity and gene flow. Expand number of species that are being studied. Harness and train local researchers in new techniques e.g. next-gen sequencing techniques, etc	Yes. Genetic work can be costly, and collection is difficult. Regional cooperation will help ease difficulties in collection and sharing of samples and associated hurdles (e.g. collection permits)
Connectivity	Studies on various aspects of connectivity of seagrass meadows within ecoregions (see Section "Thematic gaps in knowledge and information") need to be conducted. Results from these studies can (should) be used to inform management and policy decisions	Yes. In most cases, a bioregion encompasses more than one country, connectivity studies will involve data collection and sharing across national boundaries
Physiology	Plant level physiological interactions and response to anthropogenic stressors. Incorporation of physiological measures in other research areas	Yes. Cooperation in standardisation of methods and in experimental studies
Mapping	Intensive mapping needs to be carried out across the region. Harness rapid development in mapping tools – e.g. using UAVs (unmanned aerial vehicles) for obtaining multi-spectral imagery	Yes. Sharing of resources and equipment can aid faster data generation, especially for remote regions and for groups that lack funding

Table 5: Table documenting obstacles to seagrass conservation and the possible solutions.

Challenges (adapted from Fortes 2013)	Possible solutions
1) Lack of trained researchers – Knowledge and expertise is concentrated in a few institutions – Knowledge and expertise is sometimes tied with visiting researchers; little knowledge and capacity building	– Increase knowledge sharing within each country and region. – Form a network of Southeast Asian Seagrass Scientists to foster collaboration and knowledge exchange
2) Limited scope of work – Early work is largely descriptive, qualitative and does not synthesise knowledge – Lack of coordination in seagrass research themes	– Studies need to be synthesised across regions (and countries) in order for research findings to be applicable beyond the local context. – Tapping on a network of regional scientists can also help avoid duplication of work and form working groups on pressing research areas
3) Gaps in basic knowledge – Very little information on extent, status, seasonal trends, uses of seagrass beds – Very few comprehensive studies and/or experimental work on environmental and anthropogenic stressors/impacts faced in the region	– Increase in funding for basic research to plug knowledge gaps in areal extent and distributions; use new and freely available techniques. – Engage local communities and citizens in monitoring programs. – Identify regional trends in anthropogenic impacts and seagrass habitat usage (e.g. fisheries)
4) Misguided management efforts – Efforts focused on remedial or curative measures, do not address root problems – Lack of effective linkage between science, and government (management) and private sectors (industry)	– Increase education and capacity building for natural resource managers. – Build research collaborations between management agencies and research institutes – Increase private sector/industry funding for applied research
5) Lack of implementation and enforcement of environmental laws – Environmental rules and regulations are not effectively enforced and implemented – Lack of planning and enforcement in protected areas	– Increase funding for regulation and enforcement. – Co-opt local communities into regulation and enforcement in remote areas – education and awareness campaigns. – Re-examine marine reserve zoning plans to include scientific principles
6) Socio-economic and cultural disconnect – Lack of appreciation for seagrass – Lack of understanding of the usage and socio-economic value of seagrass	– Increase presence of seagrass in mainstream social media, news, education curriculum. – Increase research funding on socio-economic and cultural valuation of seagrass – Increase participatory citizen science initiatives to engage the wider public

seagrass meadows continuing to take place (e.g. Guimarães et al. 2012).

One of the major difficulties surrounding implentation and enforcement of enviromental laws is often resistance from the local seafaring communities (Bennett and Dearden 2014). This social-economic and cultural disconnect is the last challenge facing seagrass conservation (Table 5; Challenge #6). Seagrass ecosystems have been reported to be one of the least charismatic of coastal ecosystems, especially when compared to coral reefs, and this lack of charisma often translates into lack of attention, research, and conservation action (Duarte et al. 2008). To counter this, and to bring seagrass into the collective consciousness of society and government, active steps need to be taken by seagrass scientists to reach across the divide to educators, managers, and the wider public, in order to garner support for seagrass science and conservation. One of the ways of achieving this aim is to introduce natural heritage education into the school curriculum (Table 5). The development of natural heritage curriculum could potentially inculcate greater conservation values from an early age, leading to greater interest and awareness of seagrass ecosystems in the future, as well as participation in voluntary citizen science programs. The value of citizen science is widely acknowledged, with the United Nations Environment Programme emphasising the importance of public participation towards sustainability (UNEP 1995). Such initiatives provide long-term monitoring data of seagrass meadows at a much lower cost, allowing research funding to be directed at other research avenues (Theil et al. 2014). A successful example of a long-term citizen science monitoring program in Southeast Asia is TeamSeaGrass (Yaakub et al. 2014b). TeamSeaGrass is part of the Seagrass-Watch Network and the data collected by volunteers have contributed towards scientific publications (Yaakub et al. 2014c, McKenzie et al. 2016), and been shared with managers from the National Parks Board (NParks) in Singapore.

Moving forward, a road map for seagrass conservation and research in Southeast Asia is proposed (Figure 8). The road map incorporates the main challenges facing seagrass conservation as identified above (Table 5), and proposes solutions that have the potential to solve several problems and provide the proper approach to face these challenges at the same time. Three main outcomes are proposed for the conservation and management of seagrass in Southeast Asia – (1) moving towards knowledge-based decision making, (2) understanding the socio-cultural-economics of seagrass ecosystems, and (3) increase seagrass awareness and understanding. As already mentioned, several

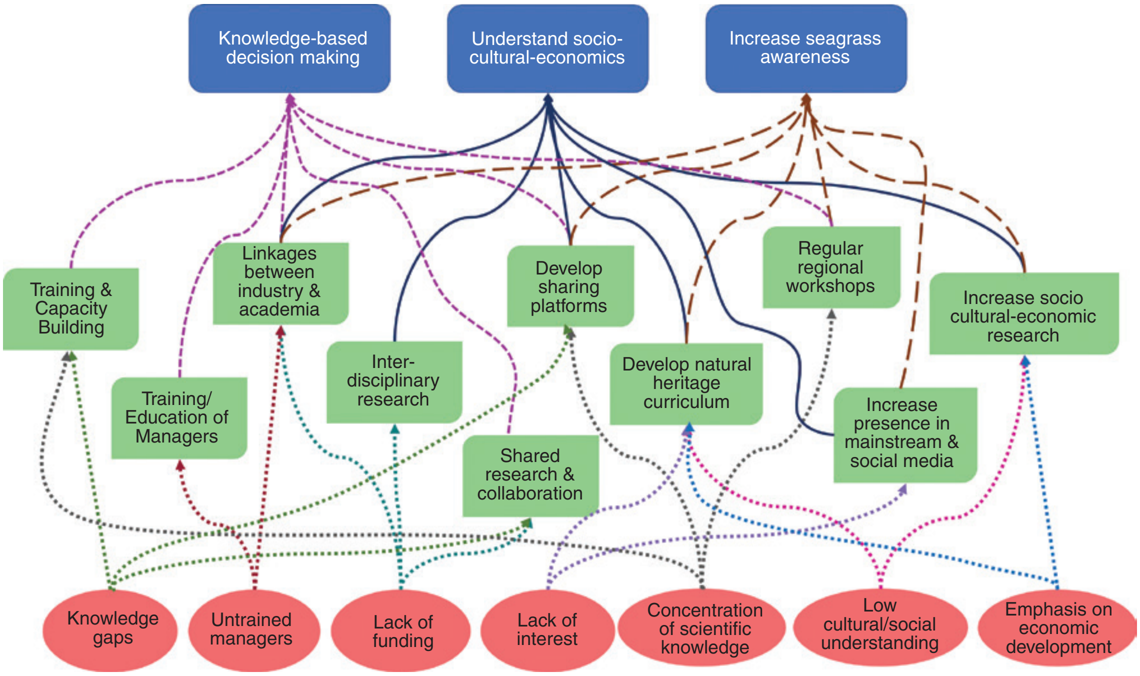

Figure 8: Roadmap for addressing conservation challenges facing seagrass in the Southeast Asian region.
Challenges can have multiple solutions and these solutions can contribute to a final aim. The challenges are listed at the bottom of the figure in red ovals and the final aims are at the top of the figure in blue boxes. Intermediate solutions are presented in the middle in green boxes. Dotted lines represent linkages betweeen the challenges and the intermediate solutions, with each dotted line colour coded specific to a challenge. Intermediate solutions that contribute to a final aim are joined by dashed and solid lines and colour coded.

challenges impeding seagrass conservation in research are interconnected. For example, knowledge gaps in the region is itself a challenge, but is also a result of other problems such as the lack of funding or lack of interest. Similarly, the solutions to these challenges are also connected. This interconnectedness allows conservation managers and other stakeholders to identify the most appropriate action to take immediately, and to prioritise conservation and management accordingly based on the specific needs of each area. This multipronged approach towards conservation and management of seagrass meadows in Southeast Asia is illustrated in Figure 8.

A roadmap for seagrass conservation and research in Southeast Asia

An example of sharing platforms would be the International Seagrasss Biology Workshop (ISBW). The ISBW series is a meeting of research scientists, students, and coastal environment managers focusing on global seagrass issues, improving seagrass knowledge, developing networks and advocating seagrass protection or conservation. Twelve ISBWs have been held and each followed individual themes reflecting both a geographical or institutional interest, and current trends in seagrass research as new knowledge and techniques became available (Coles et al. 2014). The 12th ISBW held in Nant Gwrtheyrn in North Wales focused on securing a future for seagrass. The 13th ISBW, to be held in Singapore in June 2018, will have a theme of "Translating Science into Action", and will focus on current developments in seagrass science and how it can be effectively developed into actions, programs, and policies that will aid in seagrass conservation and management. These outcomes are important, not just for the Southeast Asian region, but globally as well.

Regionally, there is the option of leveraging on existing platforms to foster sharing and cooperation, such as the Association of Southeast Asian Nations (ASEAN) Cooperation on Environment. This regional organisation holds nature conservation and biodiversity, and the coastal and marine environment as two of its seven strategic priorities (ASEAN Cooperation on Environment 2017). Getting seagrass conservation on the ASEAN environmental agenda would be a big boost in terms of fostering cooperation, collaboration, and knowledge sharing in the region. This in itself, will be an uphill task, especially since there are competing environmental issues, such as transboundary haze, which are more visible and seemingly have wider regional urgency. There are also other ASEAN-related bodies, such as the ASEAN Center for Biodiversity, which could be a smaller and more manageable platform to launch the seagrass conservation and management agenda for the region.

It is likely that the degradation of seagrass ecosystems is expected to continue, despite greater local and region-wide conservation efforts and the promises of programs and projects being implemented and planned. At present, there appear only two likely options left for us: status quo or "business as usual", wherein coastal development are intensified, but with almost complete disregard of relevant scientific knowledge and pertinent laws; or protect and enhance what remains of the ecosystem, wherein people are given the opportunity to conserve and enjoy them for themselves and the future generations. It is easy to argue in favour of a combination of these approaches, but as the past years have shown, this has been easier said than done. To our knowledge, success along this line in the region has been insignificant – in both temporal and spatial magnitude and scale – in relation to the total area of coastal space utilised and the amount of resources spent. There is an increasing likelihood that coastal environmental change will create a need for adjustments of established ecosystems on spatial and temporal scales that are unprecedented in SE Asian history. Hopefully, these adjustments are not compromises to the detriment of seagrass ecosystems.

Sound conservation and management of our seagrass ecosystems can be realised. Basic human survival as well as robust national and global socioeconomic arguments underline the compelling need for the effort. The specific interventions in improving seagrass management in the world have been spelled out even as early as the 1990s (Fortes 1991, UNEP SCS/SAP 1999) and more recently by UNEP (2012), but even with these, a secure future for the region's seagrass resources seemingly remains out of sight. Trajectories toward seagrass loss can be reversed if and when all concerned stakeholders contribute positively to the effort in reversing current coastal ecosystem degradation trends. In order to sustain the benefits we all derive from these natural assets, substantial commitments and investments must collectively be made by communities, scientists, local government units, national government agencies, and assisting organisations to effect a change from the current self-destructive course to one of conservation and sustainable use. Indeed, a transdisciplinary approach is required, with each proposed step undertaken in a holistic manner and not separately or compartmentalised. There is a great opportunity and compelling grounds for regional collaboration and cooperation to tackle the issue of seagrass conservation. It would be a tragedy to let it slip.

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