THE STATUS OF SEAGRASS MEADOWS IN THE KEP ARCHIPELAGO 2019

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Executive Summary

Seagrass is one of the most ecologically valuable marine ecosystems. This is due to the ecological services they provide, such as: sediment stabilisation, carbon sequestration, ecosystem connectivity and marine fauna habitat. Cambodia is home to twelve different seagrass species, ten of which are found in the Kep Archipelago. A Marine Fisheries Management Area (MFMA) was formally implemented within the Kep Archipelago, by the Cambodian Fisheries Administration and Marine Conservation Cambodia (MCC), in April 2018. This MFMA was established to protect and conserve important marine ecosystems from Illegal, Unreported, Unregulated (IUU) fishing activities, including bottom-trawling. The key ecosystems identified within the archipelago include seagrass meadows, coral reefs and mangrove forests. Alongside several endangered marine fauna such as, Irrawaddy dolphins (*Orcaella brevirostris*), Green sea turtles *(Chelonia mydas*) and seven species of seahorse (*Hippocampus* sp.).

This report aims to map seagrass abundance, extent, distribution and species composition within the archipelago, in order to provide important baseline data to contribute towards effective marine conservation and management strategies.

Quadratted transects were conducted, by the Seagrass Conservation Project (an MCC research programme), at three seagrass meadow fragments within the archipelago: Koh Ach Seh, Koh Poh and Koh Tonsai. These sites were previously identified through rapid habitat assessments, conducted by MCC. Surveys confirmed the distribution and extent of three seagrass meadows within the archipelago. These three meadows were located to the eastern shore of Koh Ach Seh, Koh Poh and Koh Tonsai, with an extent of ~34ha, ~487ha and ~470ha, respectively. *Thalassia hemprichii, Enhalus acoroides, Halophila ovalis* were found to be the most abundant species across the three meadows, with *Thalassia hemprichii* being the most ubiquitous. *Halophila ovalis,* a pioneer species, was found to be most prevalent at the meadow edges, suggesting that despite the persistence of destructive bottom-trawling activity, these meadows are capable of recovery and recolonisation. Bottom-trawling was actively observed during surveys and passively observed in the form of trawling tracks, except at Koh Ach Seh, where a high density of Conservation and Anti-trawling Structures are deployed and MCC presence acts as a deterrent. This evidence highlights the need for effective and enforced legislation, in order to protect these critical and threatened ecosystems.

Accurately and reliably identifying the abundance, distribution, extent and species composition of these seagrass meadows, provides the basis for continued regional monitoring, alongside the implementation and assessment of effective seagrass conservation strategies. These data also aim to contribute towards community education and community conservation initiatives, to ensure not only policy driven ecosystem protection, but also sustainable, community-led conservation action.

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Background

Southeast Asia is thought to be the centre-of-origin for tropical seagrasses, and has the greatest diversity of seagrasses within the Indo-Pacific biogeographic region (Short *et al*., 2001). Despite being amongst the most ecologically and economically valuable ecosystems on earth, seagrass meadows are declining globally at a rate of approximately 7% each year (Costanza *et al*., 1997; Waycott *et al*., 2009). Moreover, seagrass ecosystems are largely overlooked in coastal management, often due to limited social awareness of the importance of seagrass ecosystems and fragmented understanding of global extent (Unsworth *et al.,* 2018; Duarte *et al*., 2008; Grech *et al*., 2012; Nordlund *et al*., 2014). Due to numerous literature gaps, more extensive research mapping the abundance, distribution and extent of seagrass, as well as their associated ecosystem services, is required (Nordlund *et al*., 2016).

Seagrasses are marine flowering plants found in shallow coastal waters which form extensive meadows between mangroves and coral reefs in tropical regions (Green and Short, 2003; Short *et al*., 2007). Seagrass provides structural complexity to the seabed, creating breeding and nursery grounds for fish and invertebrates, and provides habitat connectivity for migrating species moving to coral reefs (Unsworth *et al*., 2006; Olson *et al*., 2019*).* In Cambodia, commercially valuable fish species and the blue swimmer crab rely on seagrass habitat for breeding, while Green turtles, (*Chelonia mydas)* and dugongs (*Dugong dugong*)*,* rely on seagrasses as a food source (Preen, 1995; Sereywath and Sokhannaro, 2003; Kaarlep, 2014). Seagrass' green leaves and rhizome network sequester carbon by removing large quantities of organic carbon from the atmosphere, locking it into the plant and surrounding sediment (Fortes, 2018). The three-dimensional structure of seagrass beds attenuate wave action and trap both sediments and nutrients, contributing to effective nutrient cycling while protecting neighboring ecosystems from the impacts of sedimentation (Hemminga and Duarte, 2000; Kennedy *et al.,* 2010; Christianen *et al.,* 2013). Seagrasses are important indicators of marine system health and are considered foundation species, enhancing ecosystem biodiversity through providing habitat to intrinsically valuable species such as the seahorse (Fortes, 2018; Curtis and Vincent, 2005*).* The Kep archipelago is home to a variety of seahorse species, with seven different species identified (Mizrahi, 2016). Seagrasses play a key role by providing habitat and protected breeding grounds for these species (Curtis and Vincent, 2005).

The ecosystem services provided by seagrasses are varied and often site-specific (Nordlund *et al*., 2016). In Cambodia, fisheries are important economic contributors to the domestic market and provide approximately 80% of animal protein to the country. This industry is crucial in providing food security, household income and livelihood options for the country's most economically vulnerable people (MAFF, 2011). In the Kep archipelago marine ecosystems provide livelihood options in the form of marine fisheries and tourism, such as recreational water sports, restaurants, hotels and vendors at the Crab Market. Marine fisheries support much of the population, where fishing vessels largely target seagrass-associated species, such as shrimp, fish and the world-renowned blue swimmer crab. In Cambodia, it has been reported that average landing of commercial catch is 125,000 tonnes per annum (PIC, 2017) with marine fisheries providing vital food sources and many essential micro-nutrients to local coastal communities (Hicks *et al.*, 2019). Furthermore, the collection of some seagrass seeds, *Enhalus acoroides,* has been reported in the Kep province (Coals, *pers. comm.,* 2020). These seeds offer an alternative source of nutrients for coastal communities (Gatta *et al*., 2020).

Most seagrass meadows are located in the intertidal to shallow-subtidal zones, exposing seagrass ecosystems to both marine and terrestrial threats, particularly as coastal ecosystems face increasing pressure from industrial development, land reclamation, nutrient influx and Illegal Unreported Unregulated (IUU) fishing activities (Harplen *et al.,* 2008; Orth *et al.,* 2006; Cullen-Unsworth *et al.,* 2014; Cullen-Unsworth and Unsworth, 2016; Grech *et al*., 2012; Short *et al.,* 2011). In Cambodia, Illegal, Unregulated, Unreported (IUU) fishing, particularly bottom-trawling, poses one of the most immediate threats to seagrass ecosystems. The direct proximal impacts of bottom trawling activities include the removal of seagrass shoots and rhizomes, damage to above-ground biomass and sediment disturbance (Sánchez Lizaso *et al.,* 1990; Neckles *et al.,* 2005; Fonseca *et al.,* 1984; Unsworth and Cullen-Unsworth, 2015; Short and Wyllie-Echeverria, 1996). The indirect impacts of these destructive fishing activities and coastal development, include: eutrophication, sedimentation, increased nutrient input and increased water turbidity. These factors reduce the availability of light for seagrass photosynthesis, resulting in inhibited seagrass growth and development (Duarte, 2002; Hemmings and Duarte, 2000; UNEP, 2008).

Cambodia's coastline stretches 440 km along the Gulf of Thailand, with Kep Province bordering Vietnam in the East. Seagrass distribution has been found to extend across the majority of Cambodia's shallow coastal waters, and is thought to be part of one of the largest seagrass areas in the world (Leng *et al*., 2014; UNEP, 2008). However, management of Cambodia's seagrass beds is currently ineffectual (Leng *et al*., 2014). The first Marine Fisheries Management Area (MFMA- Cambodia's equivalent of a Marine Protect Area) in the Koh Rong archipelago was established in 2013, and another in 2018 around the Kep archipelago, both of these areas encompass key seagrass ecosystems (Leng *et al* 2008; UNEP, 2008). The largest extent of seagrass in Cambodia is found in Kampot Province, with fragmented meadows distributed around the offshore islands of Kep Province (MFF, 2013; Sereywath and Sokhannaro, 2003; Supkong and Bourne, 2014; Vibol *et al*., 2010). Previous studies of Kep and Kampot provinces have reported the presence of 12 seagrass species (Vibol *et al*., 2010). However, more recent assessments of the current state of the Kep's seagrass meadows are required.

Marine Conservation Cambodia (MCC) is a non-government organisation established in 2008 to protect and conserve vulnerable marine ecosystems within Cambodia, and support their dependent coastal communities. MCC built on previous knowledge of the archipelago seagrass ecosystems, to form the basis community-driven conservation and ecosystem conservation policy. This report aims to contribute towards this growing knowledge base and offer current findings to support the continued and diversifying conservation efforts within the region.

Aims

This research aims to map the extent, abundance, diversity and distribution of seagrass species within the Kep archipelago, and act as the first step in the longitudinal monitoring of these seagrass meadows. In addition, this baseline study aims to contribute towards the establishment of Cambodia's coastal wide seagrass monitoring network. Through this research we aim to better consider the needs of seagrass meadows, and their dependent resource users, when developing marine management. Successful management works to protect, conserve, and build resilience in Cambodia's seagrass meadows and coastal communities.

Research

Study area

The Kep archipelago comprises 13 islands situated between 3- 13km offshore from mainland Kep The international maritime border between Cambodia and Vietnam runs along the southern edge of the archipelago. Kep's waters are shallow, reaching no deeper than 10m. Kep's MFMA was established in 2018 in order to protect and restore the Kep's marine environment. Zoning of the MFMA was designed to restrict destructive fishing activities and gear-use, and to monitor tourist activities within the archipelago. This study aims to map the seagrass meadow fragments within the MFMA, and focusses around the three main islands of the Kep archipelago; Koh Ach Seh, Koh Poh, Koh Tonsai (Figure 1).

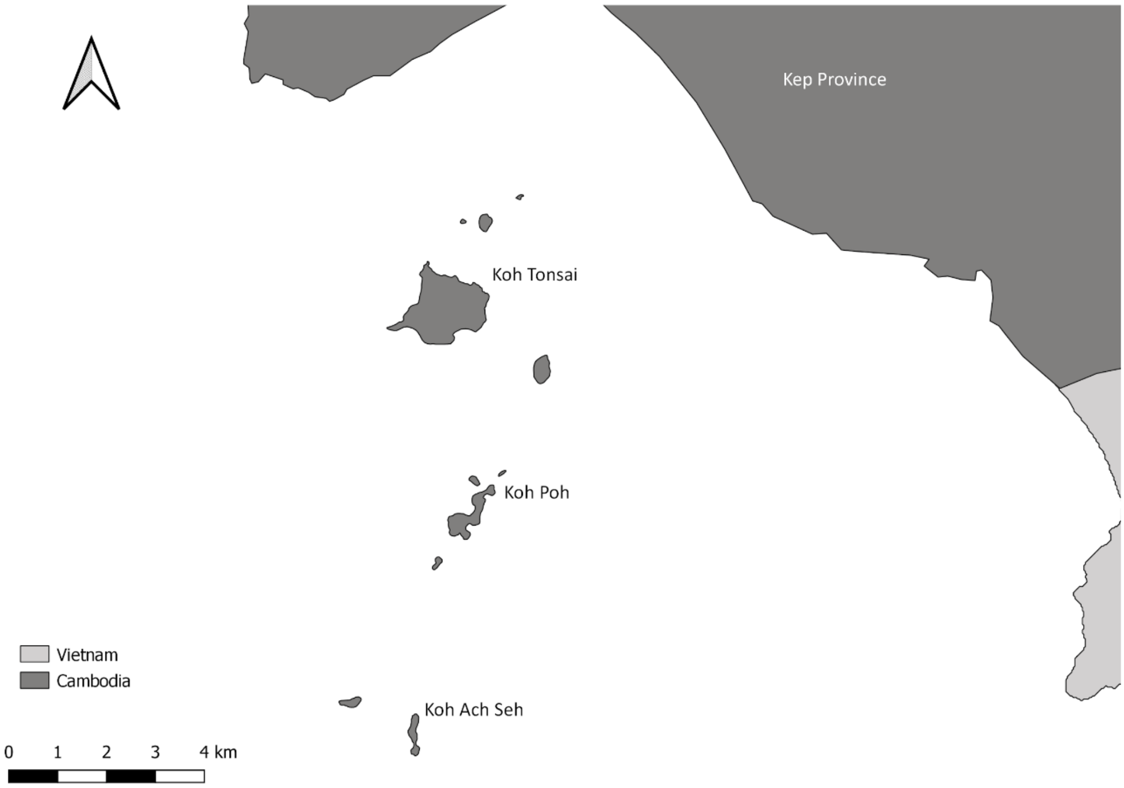

Figure 1: *Kep Archipelago, Kep Province, Cambodia; highlighting the three survey sites- Koh Ach Seh, Koh Poh and Koh Tonsai. The Kep Archipelago is bordered by Vietnam to the east, south and west.*

Study sites

Koh Ach Seh (10º 21' 27.592" N, 104º 19' 11.66" E) is the most southern island in the Kep archipelago, and is the smallest of the three main study sites. A 300m no-take zone surrounds the island, which restricts all fishing activities, except for two multi-use zones allowing vessel access to the east and west of the island. Within this multi-use zone, local artisanal fishers are able to moor on the island to seek refuge and rest. Koh Poh (10º 23' 48.932" N, 104º 19' 46.05" E) is situated 9 km from mainland Cambodia, north of Koh Ach Seh and south of Koh Tonsai. A fishing community inhabits Koh Poh, and the residents moor their vessels alongside their settlement. Koh Tonsai (10º 26' 11.28" N, 104º 19' 34.036" E) is the largest and most developed island in the archipelago, and is the only MFMA zone where tourist activities are allowed. Located 4 km from the mainland, Koh Tonsai has daily boat traffic transporting tourists to-and-from the island. Island topography is consistent across the archipelago of sandstone rock covered by littoral forest. The shallow archipelagic waters support fringing hard-coral reefs around each island. These reefs connect to seagrass meadows located along the eastern margin of each island.

Preliminary field surveys

In October 2018, MCC conducted a rapid assessment of the archipelago to assess seagrass presence. Explorative swimming and SCUBA diving transects were conducted by swimming for two minutes, recording sediment type and the presence of seagrass species at 30 second intervals. Additional recordings of any changes in the presence of seagrass species were taken between 30 second intervals. Results provided a baseline for the extent of seagrass within the Kep MFMA. The maps and data generated from these surveys were used as the foundation for subsequent, targeted survey efforts.

Generating survey points

Using QGIS (version 3.1.0), a grid was created and superimposed over the previously recorded GPS positions of the archipelagic meadows. Grids were generated for each of the three islands and extended beyond the previously marked areas containing seagrass. This was done to allow surveyors to find and confirm the location of meadow edges. The intersection of each grid square generated a UTM coordinate which was the exact site for each survey for Koh Ach Seh, and the start site for each survey at Koh Poh and Koh Tonsai.

At Koh Ach Seh, survey points were generated 50 m apart running from the reef edge along the length of the island, and in 50 m increments away from the shore (Figure 2), in accordance with the Seagrass Watch protocol (Mckenzie *et al*., 2003). Surveys at Koh Poh and Koh Tonsai were conducted as quadrated transect lines which were situated 500m apart and ran along suspected depth gradients, predominantly parallel to the East shore of each island. Survey points were spaced at 50m intervals along each 250m transect (Figure 2).

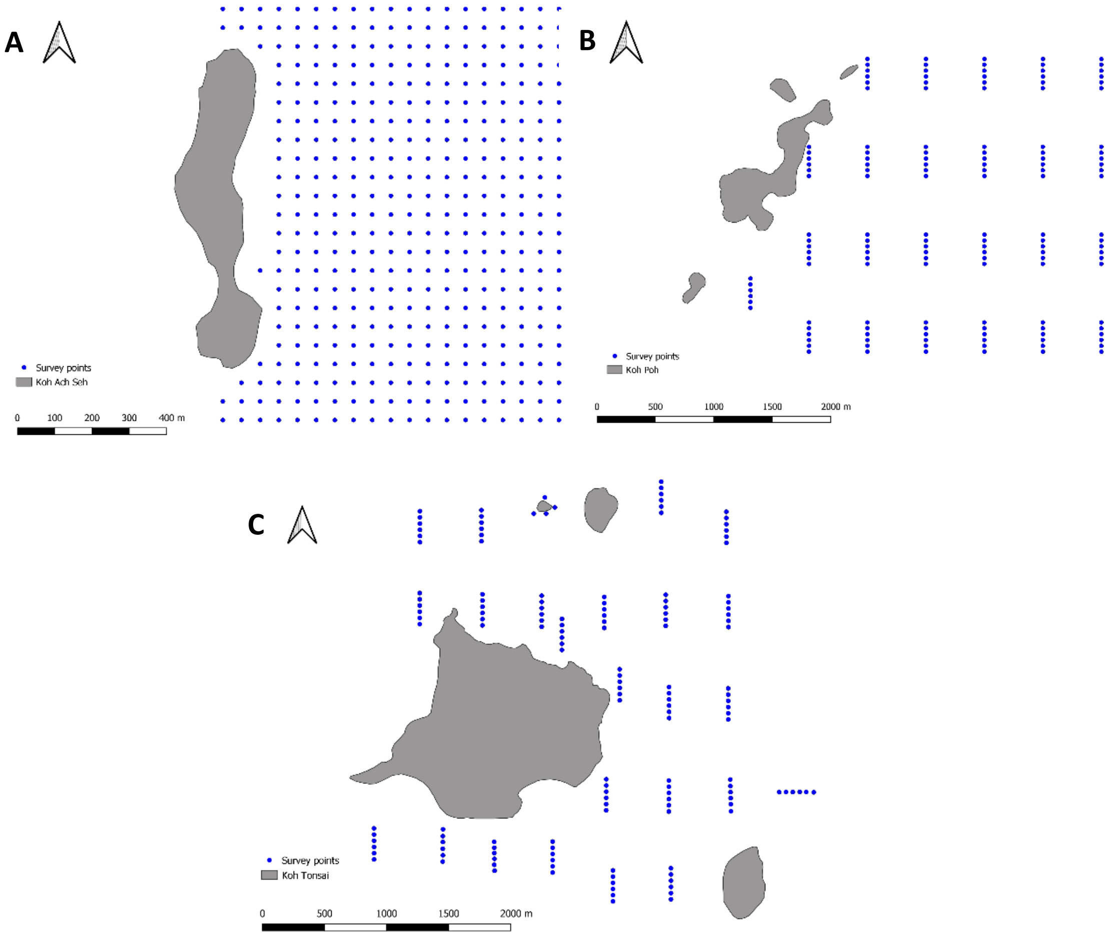

Figure 2: *A- Koh Ach Seh, three quadrats were randomly thrown at each point; B- Koh Poh, equally interspaced transects were swum and three quadrats were randomly thrown at each point; C- Koh Tonsai, equally interspaced transects were swum (plus additional two edge confirmation transects) and three quadrats were randomly thrown.*

Field surveys

Field surveys were undertaken during February, March, October and November 2019. Surveys of the subtidal meadows were conducted by SCUBA diving, due to low water visibility. The start of each transect was located using a Garmin 64x series GPS and marked with a buoy. At Koh Poh and Koh Tonsai, surveyors swam along predetermined compass bearing, conducting quadrat surveys at 50m intervals along the 250m transect. At Koh Ach Seh, each point was marked with a weighted buoy dropped from a kayak, located using the GPS. Within a 5m radius of each point, three, 0.5m^2 quadrats were randomly thrown. In each quadrat, abiotic and biotic factors were recorded; these include: water depth, substrate, percentage cover of seagrass, shoot density, height of seagrass foliage, epiphytic algal cover, damage to seagrass and trawling tracks.

Water depth was measured using a Suunto D4 dive computer. Substrate type was assessed according to the Udden-Wentworth grain size classification scale, into categories of silt, mud, fine sand, sand, coarse sand, gravel, and shell debris (Wentworth, 1922).

Total percentage cover of seagrass, percentage cover of each species (as a proportion of the total seagrass in the quadrat), shoot number of each species, and three randomly chosen leaf lengths for each species present, were recorded (Mckenzie *et al*., 2003). Seagrass species were identified by observations of leaf shape, vein patterns on leaves and rhizomes. Variations in leaf size arise due to water quality, wave action and quantity of light, therefore, these other anatomical distinguishing characteristics were used to discern each species. Epiphytic algal cover was documented as a score of more or less than 50% coverage, and used as an indicator for seagrass resilience. Shoot number and leaf length provide an indication of biomass which can be used to inform future studies on carbon capture potential. At Koh Ach Seh, once seagrass presence was not observed, one subsequent survey point was observed to confirm the meadow edge had been reached, as supported by previous baseline research (Reid *et al*., 2019). However, at Koh Poh and Koh Tonsai, all transect lines were completed regardless of an absence of seagrass, due to limited understanding of meadow expanse.

Any damage to seagrass was recorded based on observation of broken shoots, broken and exposed rhizomes, and trawling lines. Linear spaces, devoid of seagrass squashed leaf blades or presence of sediment trenches, were recorded as trawling tracks (Neckles *et al*., 2005; González-Correa *et al*., 2005). The presence of fishing nets and traps were also noted during surveys.

Additional spot checks were conducted to confirm meadow extent and meadow edge.

Data analysis

Data were inputted into QGIS (V3.0.1.) to determine the extent of meadows and to visualize the relationship between location and seagrass cover.
Species richness for the Kep archipelago and each seagrass meadow fragment were calculated. The Shannon index was used to determine seagrass diversity scores for each of the meadows. The Kolmogorov-Smirnov test was used to assess the normality of seagrass percentage cover and shoot density. Kendall Tau-b correlation coefficient assessed the relationship between seagrass abundance and depth of water according to mean percentage cover of biomass per survey point, and mean shoot density per survey point. Mean foliage length was calculated for *Thalassia hemprichii* and *Halophila ovalis* to describe biomass length observed along a depth gradient. Substrate type and epiphytic algal cover were tallied and displayed as percentages across all survey sites. Incidences of damage to seagrass were tallied across all surveys of the archipelago.

Results

1.0. Extent

1.1. Total Extent

The total extent of seagrass across the Kep archipelago was recorded at ~991 ha (Figure 3). Survey efforts focused around three main study islands, with some exploration of connectivity between meadow fragments. Observations found limited connectivity between the islands. However, stable substrate and connective meadow growth was found in the shallow coastal waters extending towards Kep mainland.

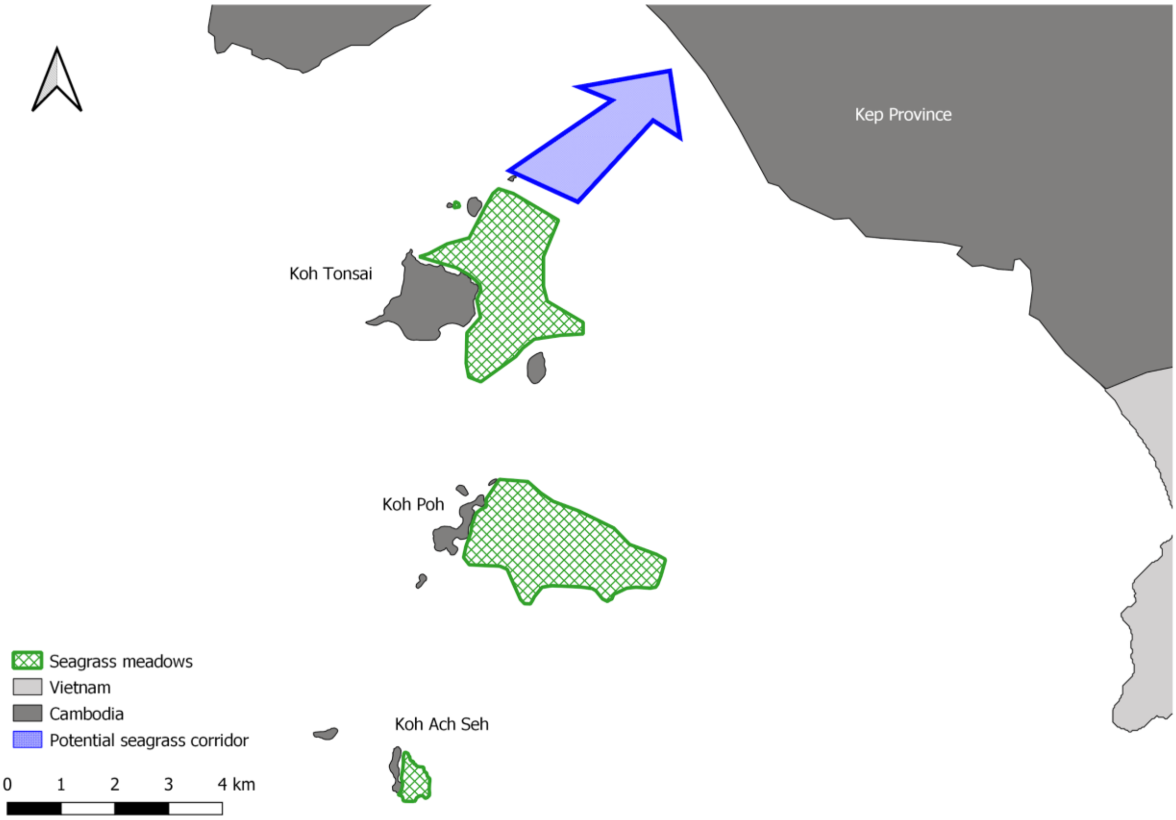

Figure 3: *Cross-hatched green area shows the extent of each of the three seagrass meadows in the Kep archipelago, to the east of Koh Ach Seh, Koh Poh and Koh Tonsai. The green border shows the meadow edges. Blue arrow indicates potential connective seagrass growth between Koh Tonsai and Kep provincial coastline.*

1.2. Meadow extents

Seagrass distribution around Koh Ach Seh was observed to span from north to south, 900 m along the length of the island, and extend 550 m East from Koh Ach Seh shore (Figure 4). The total area of Koh Ach Seh seagrass meadow was ~34 ha.

Koh Poh seagrass meadow was recorded to range from the eastern shore to ~3.8km offshore. The total area covered by seagrass was recorded at ~487 ha (Figure 5).

Seagrass meadow surrounding Koh Tonsai was found fringing the northern shore, extending 1.3km east from the island and north east towards mainland Kep. The total area covered by seagrass, surrounding Koh Tonsai, was recorded at ~470 ha (Figure 6).

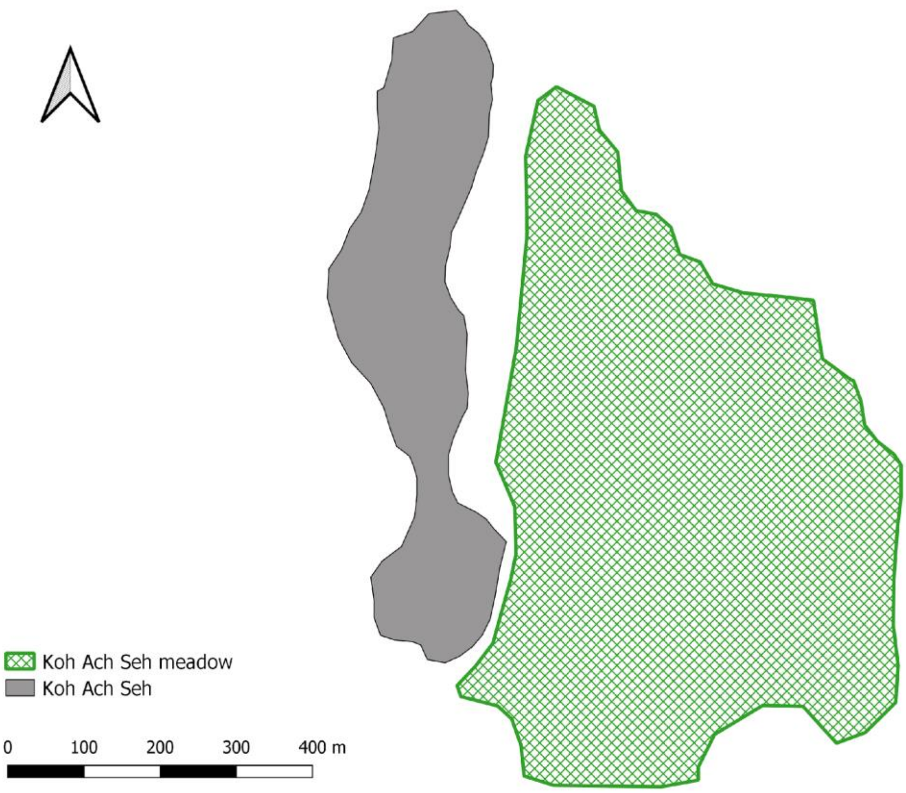

Figure 4: *Cross-hatched green area shows the extent of seagrass meadow to the east of Koh Ach Seh. The green border shows the meadow edge.*

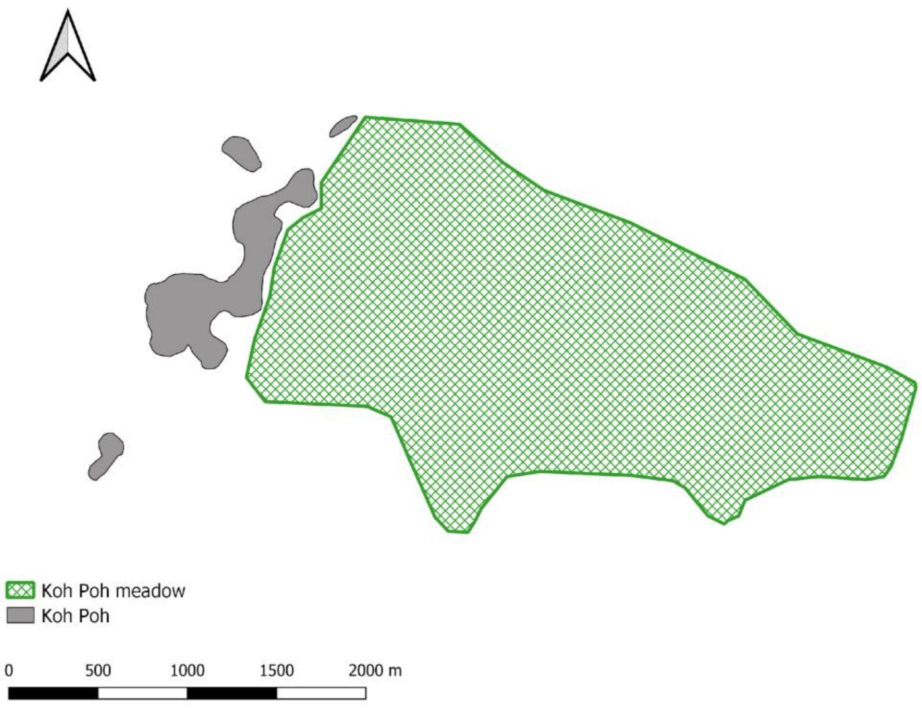

Figure 5: *Cross-hatched green area shows the extent of seagrass to the east of Koh Poh. The green border shows the meadow edge.*

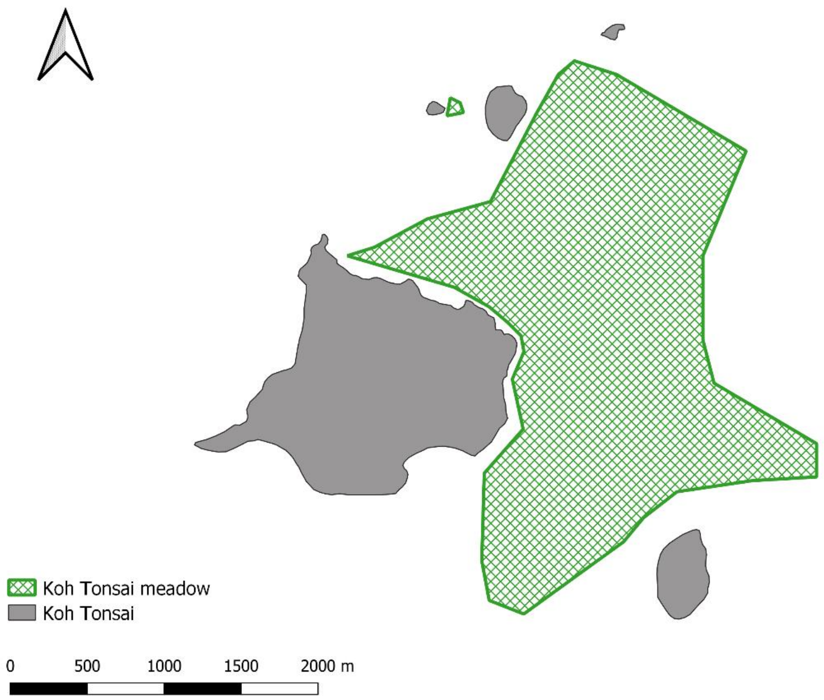

Figure 6: *Cross-hatched green shows the extent of the seagrass meadow east of Koh Tonsai. The green border shows the meadow edge.*

2.0. Species richness and diversity

2.1. Species richness

The species richness of the Kep archipelago meadows is 10 seagrass species. These heterogeneous meadows support *Thalassia hemprichii, Enhalus acoroides, Cydomocea serrulata, Cydomocea rotundata, Halodule pinifolia, Halodule uninervis, Halophila ovalis*, *Halophila decipiens, Halophila minor and Syringodium isoetifolium.*
A total of eight seagrass species were recorded at Koh Ach Seh and Koh Tonsai, while Koh Poh meadow supports seven species. All species were observed in at least two of the three meadows, with the exception of *Halophila minor* and *Syringodium isoetifolium*.

2.2. *Species diversity*

Koh Tonsai had the highest diversity of seagrass species and most equally distributed community structure of the three meadows (H= 1.46, E= 0.70). Koh Poh had the lowest seagrass diversity and community evenness (H= 0.934, E= 0.48). Koh Ach Seh (H= 1.31, E= 0.63) seagrass meadow was more diverse and even than Koh Poh, but less so than Koh Tonsai.

Across the three meadows, *Thalassia hemprichii* was the ubiquitous species, observed at 80% of the sites where seagrass was present. *Enhalus acoroides* distribution was observed as patches throughout meadows, with particularly dominant, homogeneous growth along shallow coastline areas around northern Koh Tonsai. *Enhalus acoroides* growth was observed at 19% of the sites with seagrass present. *Halophila ovalis* was observed at 21% of sites containing seagrass, with notable presence towards meadow edges with evidence of previous seagrass damage, silt substrate, and deep water. *Halophila minor* and *Syringodium isoetifolium* were observed least frequently, and only located in the Koh Poh meadow.

3.0. Abundance

Thalassia hemprichii, Halophila ovalis and *Enhalus acoroides* were the species most frequently observed in the archipelago. *Halophila minor, Halodule pinifolia* and *Syringodium isoetifolium* were observed least frequently, and were least abundant when observed (Figure 7).

Rank	Koh Ach Seh	Koh Poh	Koh Tonsai
1	*Thalassia hemprichii*	*Thalassia hemprichii*	*Thalassia hemprichii*
2	*Halophila ovalis*	*Halophila ovalis*	*Enhalus acoroides*
3	*Halophila decipiens*	*Cydomocea serrulata*	*Cydomocea serrulata*
4	*Halodule uninervis*	*Enhalus acoroides*	*Halophila ovalis*
5	*Cydomocea serrulata*	*Halodule uninervis*	*Halophila decipiens*
6	*Cydomocea rotundata*	*Syringodium isoetifolium*	*Halodule uninervis*
7	*Enhalus acoroides*	*Halophila minor*	*Cydomocea rotundata*
8	*Halodule pinifolia*		*Halodule pinifolia*

Figure 7: *Seagrass species observed at each island and ranked according to frequency of observation.*

3.1. Percentage cover

Seagrass percentage cover and shoot density were used as measures of abundance, and were both found to be non-normally distributed, therefore Kendall's Tau-b test was used.

Using a Kendall's Tau-b test, a negative correlation ($_T$b-0.489, *n*= 498, p<0.01), between total percentage cover of seagrass and depth, was found across the Kep archipelago, which indicates that seagrass cover decreased as depth increased (Figure 8).

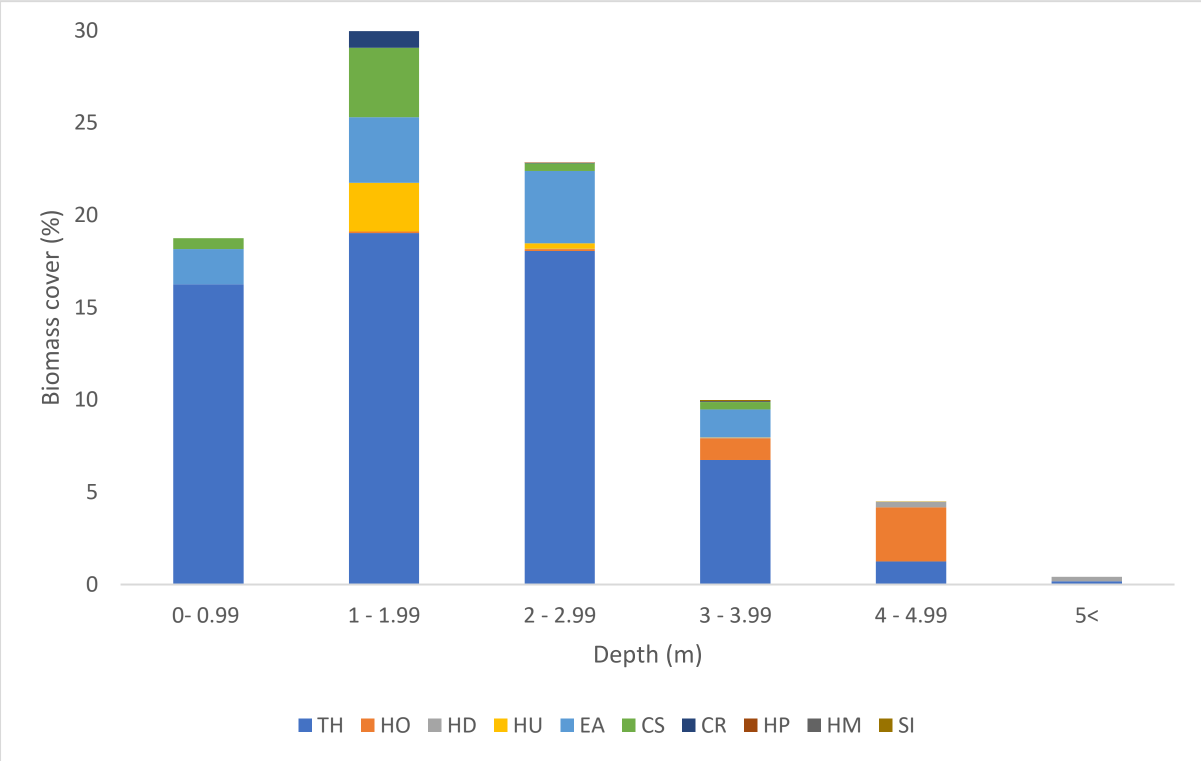

Figure 8: *Mean percentage of biomass cover of each seagrass species observed across the three meadows, according to depth. TH-* Thalassia hemprichii; *HO-* Halophila ovalis; *HD-* Halophila decipiens; *HU-* Halodule uninervis; *CS-* Cydomocea serrulata; *CR-* Cydomocea rotundata; *EA-* Enhalus acoroides; *HP-* Halodule pinifolia; *SI-* Syringodium isoetifolium; *HM-* Halophila minor.

A negative correlation, between seagrass percentage cover and water depth, was found at each of the three meadows; Koh Ach Seh meadow ($_T$b = - 0.466, *n*=175, p<0.01) Koh Poh ($_T$b = - 0.439, *n*=159 p < 0.01) and Koh Tonsai ($_T$b = - 0.536, *n*=164 p < 0.01).

At Koh Ach Seh and Koh Tonsai, the mean percentage cover of seagrass was observed to be highest at depths between 1 - 2 m, and at Koh Poh, this was between 2- 3m.

Depths below 1 m were only located at Koh Tonsai, where *Thalassia hemprichii* was the most abundant species, with an average of 48% biomass cover from sites where seagrass was present (Figure 9C). *Enhalus acoroides* had an average biomass cover of 5% at this depth, and *Cydomocea serrulata* was observed at 3% cover.

At depths **between 1-1.99m** seagrass observations were made at Koh Ach Seh and Koh Tonsai. *Thalassia hemprichii* mean biomass coverage was 13% at Koh Ach Seh, and 54% cover at Koh Tonsai. At Koh Tonsai, *Enhalus acoroides, Cydomocea serrulata, Halophila uninervis* and *Cydomocea rotundata* were also present. Observations of *Cydomocea serrulata* had a mean abundance of 37% cover at depths between 1 and 1.99 m. *Enhlaus acoroides* was observed at 12 survey points, with an average of 12% cover, and a maximum of 40% cover (Figure 9C). Koh Ach Seh species richness was five species at this depth, and included*, Thalassia hemprichii, Halodule uninervis, Cymodocea serrulata, Cymodocea rotundata* and *Halophila ovalis. Cydomocea serrulate, Thalassia hemprichii* and *Halodule uninervis* were the most abundant species at this depth, with mean coverages 15%, 13% and 12%, respectively (Figure 9A).

At depths of 2-2.99m *Thalassia hemprichii* was the most abundant species in all of the meadows (Figure 8). Observations at Koh Poh found mean *Thalassia hemprichii* cover to be 25%, while at Koh Tonsai, 24%, and Koh Ach Seh, 17% (Figure 9). No other species were observed at this depth at Koh Poh. All eight species were observed at Koh Ach Seh meadow including patches of *Enhalus acoroides* with maximum cover of 70%. All other species were found at low abundances, each less than 5% mean cover. *Enhalus acoroides, Halodule pinifolia, Halodule uninervis, Cydomocea serrulata* were observed at Koh Tonsai, with *Enhalus* the second most abundant species behind *Thalassia hemprichii,* with mean biomass cover of 14% (Figure 9C). The highest abundance of *Enhalus acoroides* was observed as 60% cover at 2.9m.

Observations at **depths between 3-3.99m** found *Thalassia hemprichii* to be most dominant, however, as depth increased *Thalassia hemprichii* abundance decreased (Figure 8). *Thalassia hemprichii* was most abundant at Koh Poh, with 12% mean cover, and 11% and 3% mean cover at Koh Tonsai and Koh Ach Seh, respectively. At Koh Tonsai, *Cydomocea serrulata* mean percentage cover was found to be 11% and *Enhalus acoroides* cover 10%. The abundance of *Halophila ovalis* and *Halophila decipiens* was below 6% at all three meadows. Koh Poh meadow supported seven species at this depth including, *Thalassia hemprichii, Halophila minor, Halophila ovalis, Halodule uninervis, Enhalus acoroides, Cydomocea serrulata* and *Syringodium isoetifolium;* however, despite the high species richness observed at Koh Poh, individual abundance of each species, other than *Thalassia hemprichii,* was less than 5% mean cover (Figure 9B).

At 4m, species dominance shifted from *Thalassia hemprichii* to *Halophila ovalis* across all the meadows (Figure 8). *Halophila ovalis* abundance was highest at Koh Poh, with an average 8% biomass coverage (Figure 9B). *Thalassia hemprichii* mean cover was less than 5% across each of the meadows. *Halophila decipiens* was observed at both Koh Ach Seh and Koh Tonsai, as well as *Halodule uninervis* at Koh Ach Seh where both species' abundances were below 2% mean cover (Figure 9A,C).

Archipelagic waters **deeper than 5m** were largely devoid of seagrass with highest biomass cover recorded at 1% of *Halophila decipiens* and *Thalassia hemprichii* across the three meadows.

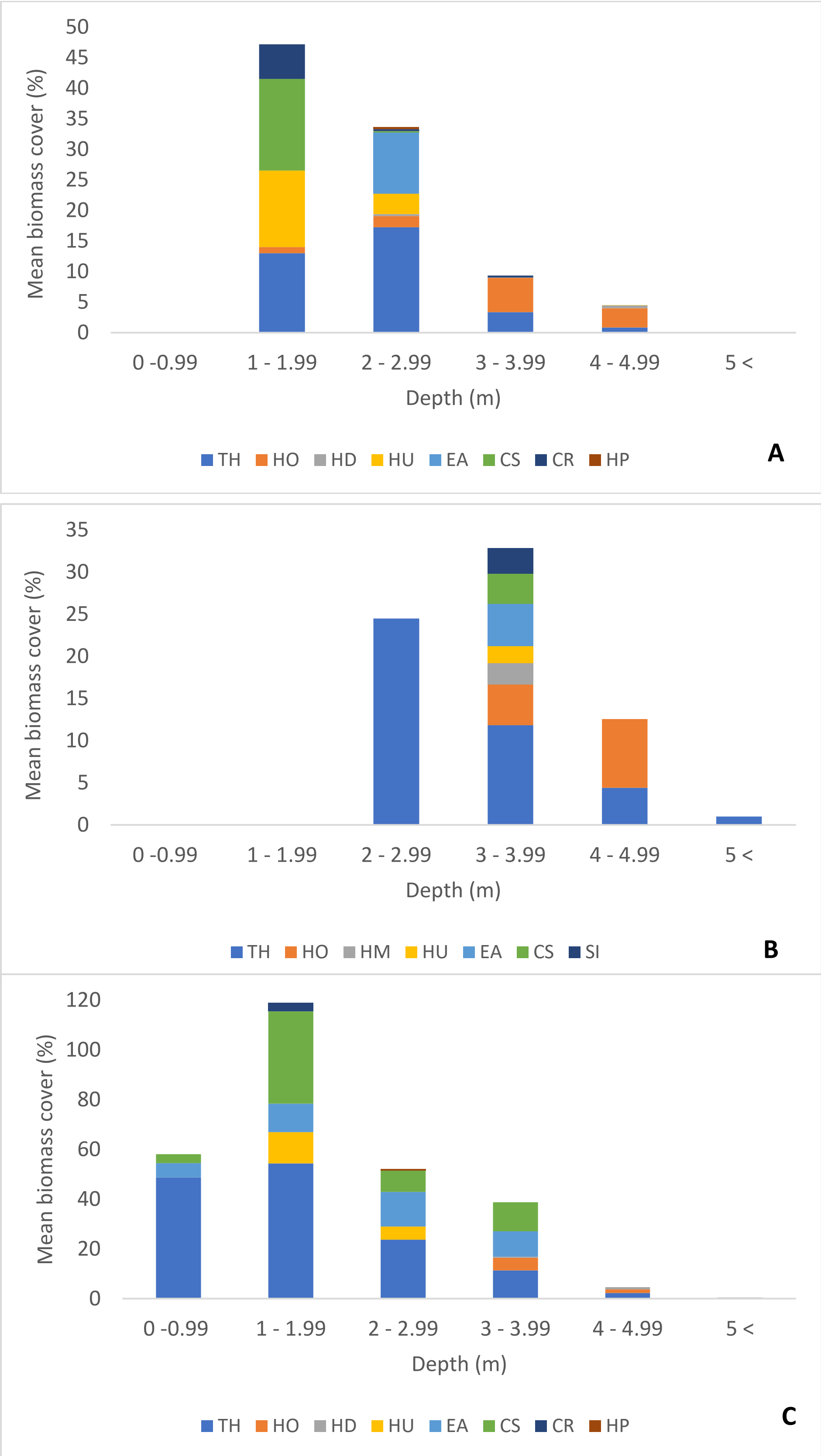

Figure 9: *Mean percentage cover of each seagrass species observed. A- Koh Ach Seh; B- Koh Poh; C- Koh Tonsai. TH-* Thalassia hemprichii; *HO-* Halophila ovalis; *HD-* Halophila decipiens; *HU-* Halodule uninervis; *CS-* Cydomocea serrulata; *CR-* Cydomocea rotundata; *EA-* Enhalus acoroides; *HP-* Halodule pinifolia; *SI-* Syringodium isoetifolium; *HM-* Halophila minor.

3.2. Shoot density

Shoot density had a negative correlation with water depth across the three seagrass meadows; where water depth increased, the total shoot density significantly decreased ($_{T}$b= -0.414, *n*=, p< 0.01; Figure 10).

Kendall's tau-b correlation displayed a negative relationship between water depth and *Thalassia hemprichii* shoot density. As water depth increased, the shoot density of *Thalassia* decreased ($_{T}$b= - 0.414, n=502, p<0.01). This relationship was not observed with *Halophila ovalis* shoot density and water depth, and only a very slight negative correlation coefficient ($_{T}$b = -0.025) was found.

The abundance of seagrass assessed by biomass percentage cover, and shoot density indicate that seagrass is most abundant at depths of between 0.4 and 3m.

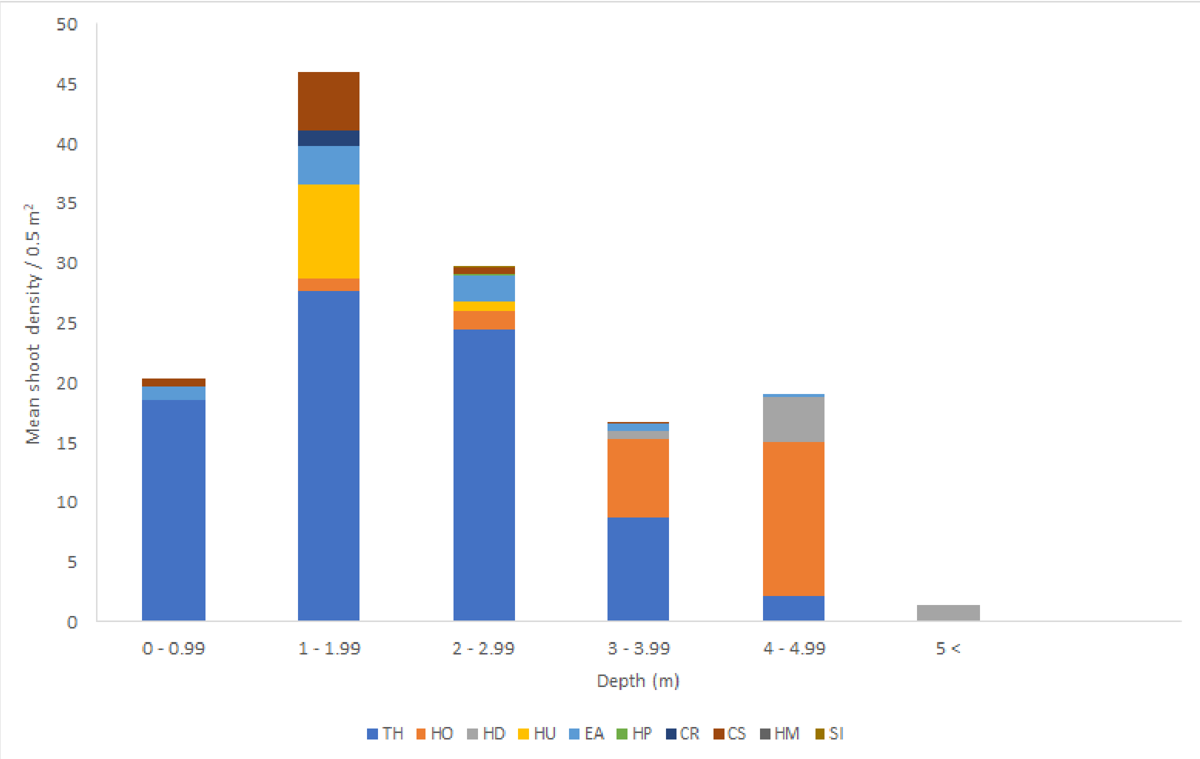

Figure 10: Mean shoot density of each species across the three meadows, according to depth. *TH*- Thalassia hemprichii; *HO*- Halophila ovalis; *HD*- Halophila decipiens; *HU*- Halodule uninervis; *CS*- Cydomocea serrulata; *CR*- Cydomocea rotundata; *EA*- Enhalus acoroides; *HP*- Halodule pinifolia; *SI*- Syringodium isoetifolium; *HM*- Halophila minor.

4.0. Seagrass distribution: site descriptions

4.1. **Koh Ach Seh**: At Koh Ach Seh, seagrass was observed continuously from the north to the south of the island, on the eastern side along the length of the island (Figure 11). *Thalassia hemprichii* was the dominant species, with a maximum cover of 75%. This *Thalassia hemprichii* dominated meadow fragment was interspersed with patches of *Halophila ovalis* and *Enhalus acoroides.* In the north of the meadow and at the meadow edge, *Halophila* was frequently interspersed with *Thalassia hemprichii,* or dominating, respectively. *Enhalus acoroides* was limited to isolated patches with a radius of 2 - 5 m. These patches were dispersed discontinuously across the meadow. *Cydomocea rotundata* and *Cydomocea serrulata* were also distributed in patches across the meadow, but were more frequently observed in the southern half of the meadow. *Halodule pinifolia* and *Halodule uninervis* were also found, fringing the southern shoreline of Koh Ach Seh. *Halophila* was most prevalent in the north of the meadow, towards the eastern edge. *Halophila ovalis* and *Halophila decipiens* were located in degraded areas with silt dominant substrate, along the eastern edge. Species richness was highest along the south-eastern edge of the meadow, within 50 m of Koh Ach Seh shoreline.

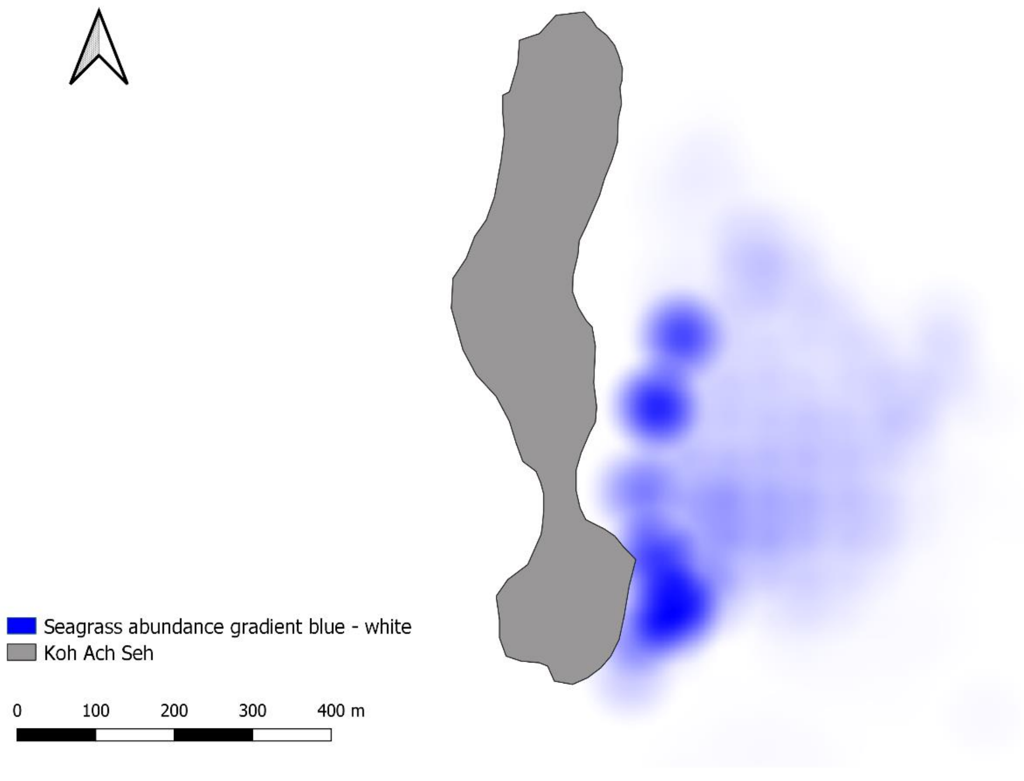

Figure 11: *Seagrass abundance (all species) east of Koh Ach Seh. Heatmap gradient: blue (most abundant) to white (least abundant).*

4.2. **Koh Poh***:* Koh Poh seagrass meadow fragment was observed continuously along the eastern shore of the island, and extended ~3.8km east offshore (Figure 12). *Thalassia hemprichii* average cover was found to be highest at 40% cover at depth of 3.5m. The most diverse locations were observed in the north section of the meadow; one close to shore and sheltered by the island, the other situated at the same latitude 2 km east of Koh Poh, at depths between 2.5 m and 3.5 m. Seagrass was only observed at 43% of surveyed sites, with seagrass presence diminishing toward the south of the island where anthropogenic activities are most prevalent. *Cydomocea serrulata* was predominantly observed within 100m from shore, in the most diverse portion of the meadow, where *Thalassia hemprichii, Halophila ovalis* and *Enhalus* were also observed. *Halophila ovalis* was dispersed throughout the meadow with a maximum biomass cover of 25%. Sightings of *Halodule uninervis, Halophila minor* and *Syringodium isoetifolium* were rare across the meadow, with a maximum cover below 5% each. Koh Poh had the greatest depth variation of the study sites, ranging between 2.1 m to 8.2 m, with substantial sedimentation around the edge of the meadow.

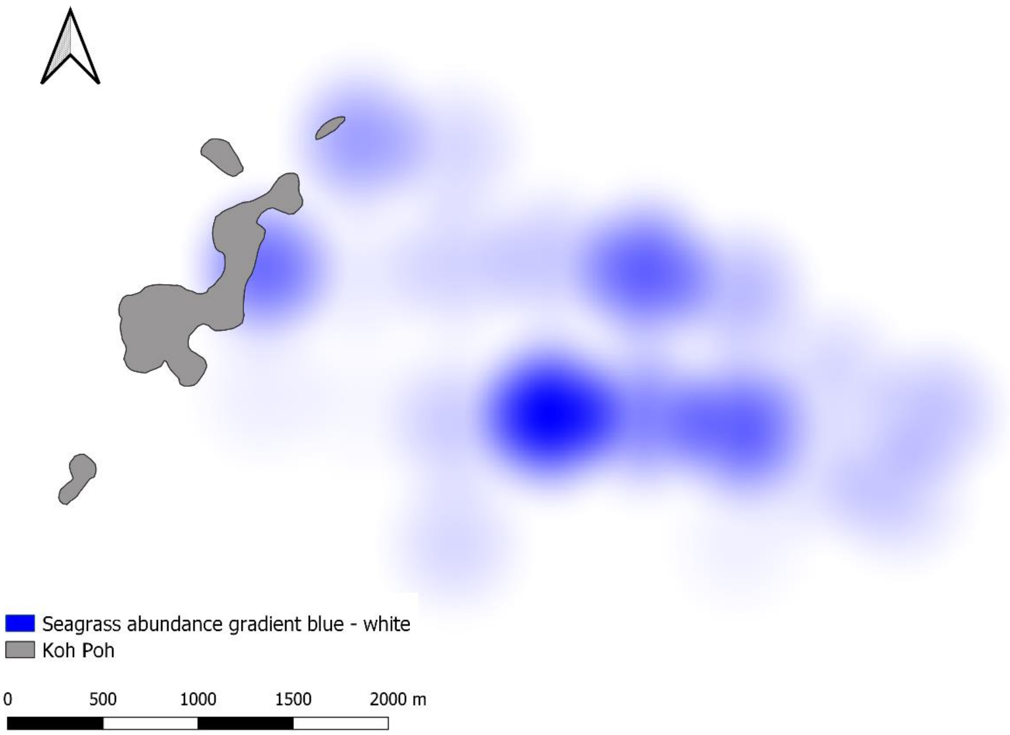

Figure 12: *Seagrass abundance (all species) east of Koh Poh. Heatmap gradient: blue (most abundant) to white (least abundant).*

4.3. **Koh Tonsai**: *Enhalus acoroides* abundance was recorded at 60% cover within 500m of the north coast of Koh Tonsai, and was distributed across the shallow waters along the east coastline (Figure 13). Seagrass abundance largely followed the depth gradient north of the island, with *Enhalus acoroides* abundance diminishing as depth and distance from shore increased. *Thalassia hemprichii* was observed in patches and was often dispersed between *Enhalus acoroides* shoots in the northern and shallow eastern shore sections. In the shallow water along the east coast of Koh Tonsai, between 0.4 m and 1.5 m, total seagrass cover was observed to be as high as 80% biomass cover. This heterospecific meadow stretched 1 km east of the island and consisted of predominantly *Thalassia hemprichii, Enhalus acoroides, Cydomocea serrulata* and *Halodule uninervis.* In areas where *Thalassia hemprichii* abundance dominated, the abundance of *Enhalus acoroides* declined and vice versa. *Halophila ovalis* was scarcely present within the main meadow, and *Halophila decipiens* was only observed in heavily degraded, silt dominant areas, with few other marine biota present. The most diverse seagrass locations were along the eastern coast of Koh Tonsai, between 0.1 km and 3.5 km offshore.

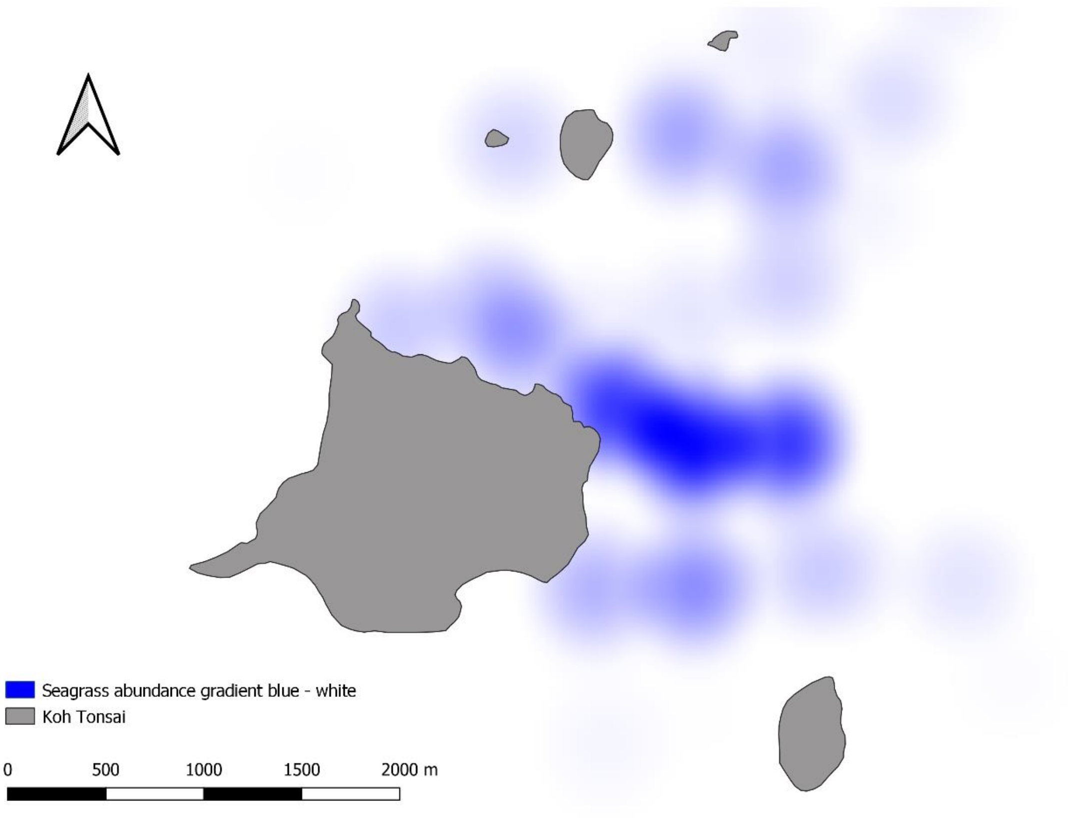

Figure 13: *Seagrass abundance (all species) east and north of Koh Tonsai. Heatmap gradient: blue (most abundant) to white (least abundant).*

5.0. Foliage length

Thalassia hemprichii and *Halophila ovalis* were used as indicator species for foliage length, and showed that mean foliage length increased with water depth (Figure 14). The mean length of *Thalassia hemprichii* ranged from 7.89 to 11.21cm, depending upon depth (1-2m and 4-5m, respectively). *Halophila ovalis* mean length also increased as water depth increased. Mean *Halophila ovalis* length ranged from 1.44cm between 1-2m and 2.36cm between 4-5m depth (Figure 15). The deepest specimen was found at Koh Poh, at a depth of 5.7m. However, this *Thalassia hemprichii* sample was broken, and measured 0.7 cm in length.

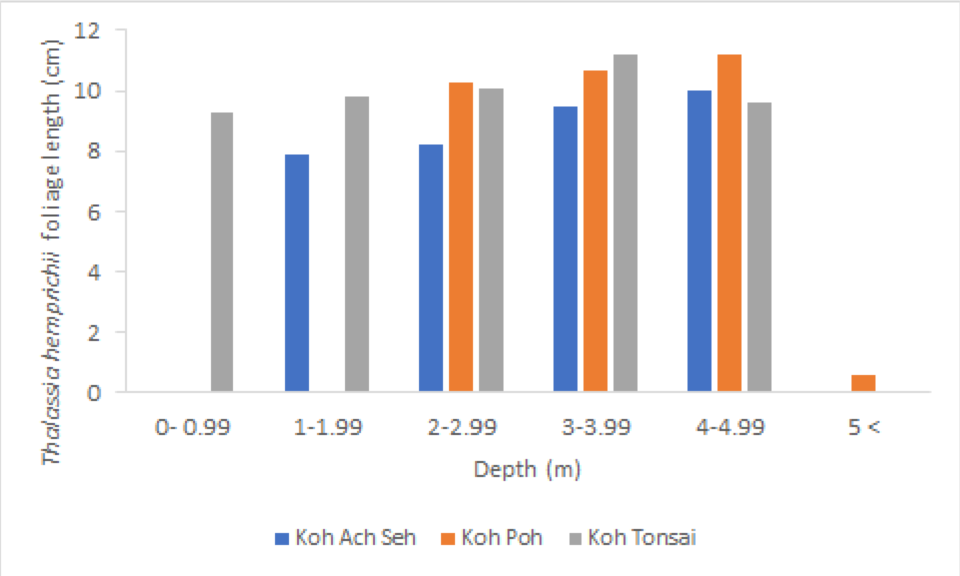

Figure 14: *Foliage length of* Thalassia hemprichii *(slow-growing indicator species) at each island, according to depth.*

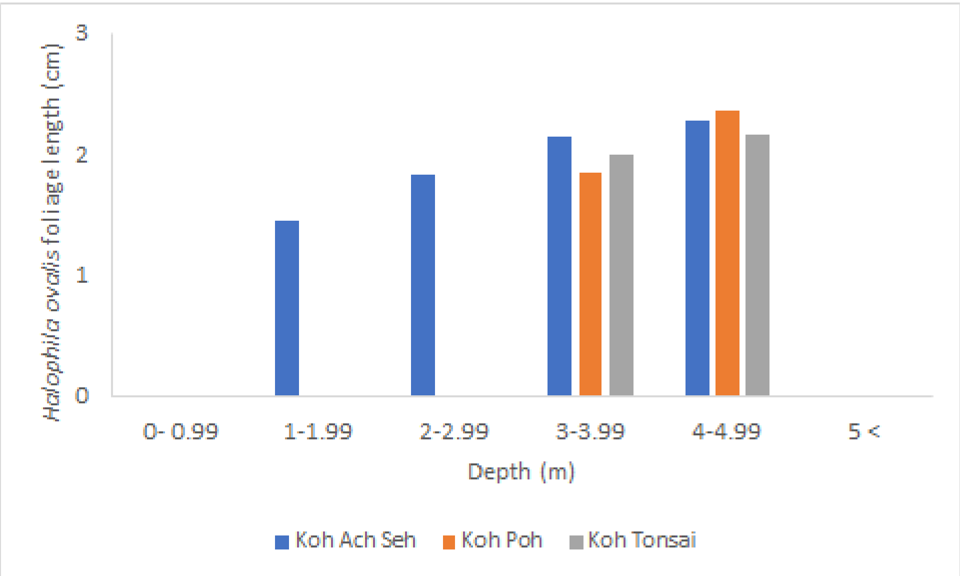

Figure 15: *Foliage length of* Halophila ovalis *(pioneer species indicator) at each island, according to depth.*

6.0. Substrate

Coarse sand, fine sand and sand were the dominant substrates across the archipelago, with 59% of the sites with seagrass present consisting of sand-type substrates (Figure 16). Silt was recorded at 35% of all surveyed points across the archipelago, and at 29% of the sites with seagrass present. Gravel, mud and shell debris were observed at 13% of the sites where seagrass was present.

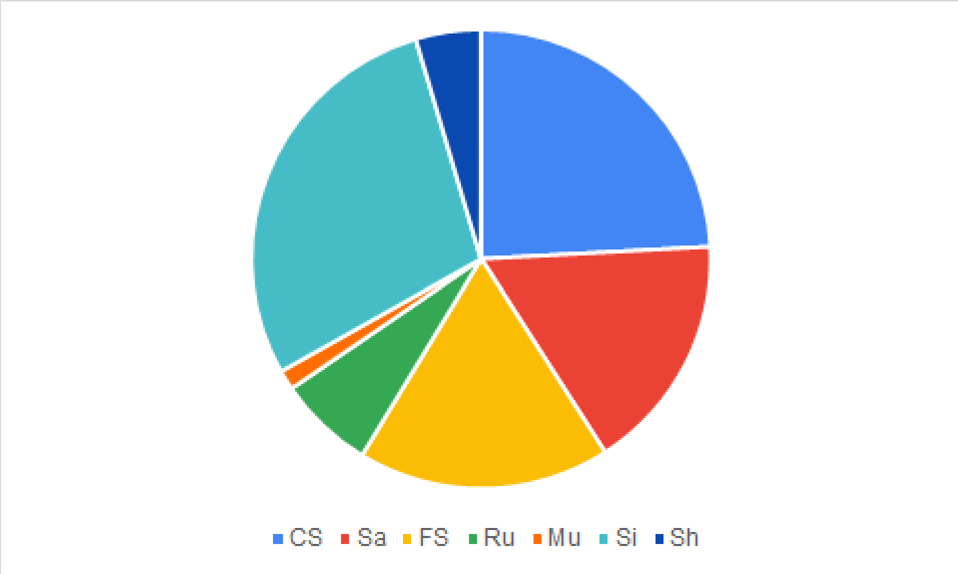

Figure 16: *Presence of substrate type at each all sites with seagrass presence. CS- Coarse Sand; Sa- Sand; FS- Fine Sand; Ru- Rubble; Mu- Mud; Si- Silt; Sh- Shell.*

7.0. Epiphytic algal cover

Seagrass with epiphytic algal cover of over 50% was observed on 75% of the surveyed seagrass. Epiphytic algal cover over 50% was observed at an average depth of 3.7m. Seagrass with epiphytic algae under 50% coverage was observed in shallower water, with a mean depth of 2.7m.

8.0. Damage

During these preliminary surveys, damage caused to seagrass by bottom-trawling activity was assessed. A total of 13 trawling tracks were observed within Koh Tonsai meadows and three were observed at Koh Poh. Trawling tracks were observed most frequently at Koh Tonsai, and were located in water between 3.2 to 4.5 m deep. At Koh Poh, trawling lines were also recorded at depths between 3.7 and 4.5m. Active trawling was commonly observed at Koh Poh during surveys, but trawling tracks could not be accurately located. No trawling tracks were observed at Koh Ach Seh meadow.

Discussion

The extent of seagrass in the Kep archipelago was found to cover approximately 991 hectares, with the largest meadow fragments surrounding Koh Poh and Koh Tonsai. These meadows contribute to the 33,814 ha of valuable seagrass meadows which have been reported to extend along the Cambodian coastline (Leng *et al.,* 2014). Koh Tonsai is the largest and most developed island in the Kep archipelago, and is one of the biggest tourist attractions of Kep province (Asian Development Bank, 2013). The Kep MFMA zoning allows for tourist activities, such as snorkeling and recreational fishing, around Koh Tonsai. These activities depend on seagrass as habitat for fish and to stabilise sediment. Sediment stabilisation ensures water clarity, increasing the productivity of benthic habitats, and is aesthetically attractive for tourism (Daby, 2003; Gössling *et al*., 2006). The myriad ecosystem services provided by the Kep archipelago meadows are critical in supporting the social and economic resilience of local coastal communities. Maintaining undisturbed seagrass meadows, large enough to support natural edge transition zones, are vital for sustaining seascape architecture and ecological processes, such as fish population dynamics (Carroll *et al*., 2019; Mahoney *et al*., 2018; Vonk *et al*., 2010). It is therefore crucial to account for the size of seagrass habitats when planning conservation action and preservation activities to safeguard both the social and ecological aspects of seagrass systems (Cullen-Unsworth *et al*., 2014; Prado *et al*., 2008).

The mixed meadows of the Kep archipelago support ten seagrass species. Of the 12 species previously recorded in Cambodia (Fortes *et al*., 2018), only two species were not observed in the Kep archipelago; *Ruppia maritima* and *Halophila beccari.* These species have, however, been recorded in the neighbouring province of Kampot (Supkong and Bourne, 2014; Vibol *et al*., 2010). The high species richness of the Kep archipelago meadows is expected, due to the historical connectivity of these meadows to the fringing meadows of coastal Cambodia, these fragmented meadows combined amount to one of the largest and most diverse seagrass meadows in South East Asia (UNEP, 2008; Vibol *et al*., 2010).

Koh Tonsai supports eight species and the highest diversity score (H= 1.46, E= 0.70) of the archipelago's meadows. The size of Koh Tonsai meadow and its proximity to mainland Cambodia provide the greatest potential for genetic drift and transportation of plants and pollen from other coastal meadows. The shallow waters along the eastern shore of Koh Tonsai also provide protection to seagrass beds by restricting boat access, thus limiting damage caused by propellers and fishing gear. Despite exhibiting the lowest diversity score, (H= 0.934, E= 0.48) Koh Poh meadow is a critical resource which provides food security to the resident fishing communities inhabiting the island. The implementation of a refugia zone within the MFMA formally acknowledges the importance of this meadow as a key breeding ground for blue-swimmer crab and other valuable fisheries species. However, a concerted effort is required to halt any further declines in meadow extent, seagrass diversity and abundance. Koh Ach Seh meadow also supports eight seagrass species, and a middling diversity score of the three islands (H= 1.31, E= 0.63). The heterogeneity of the three meadows provide structural complexity through diverse seagrass morphological characteristics. This heterogeneity, and the resultant structural complexity, enable an array of important ecological processes, such as trophic cycling. Therefore, a high seagrass diversity and 3-dimensional structure has been shown to benefit seagrass associated fish populations, and as a result, support coastal communities' livelihoods and food security (Hori *et al*., 2009; de la Torre-Castro, 2014).

Seagrass conservation around the island of Koh Ach Seh has proven successful due to the deterring presence of MCC, the high deployment density of Conservation and Anti-Trawling Structures and the implementation of a 300m no-take zone around the island. These structures help stabilise substrate and prevent direct damage to seagrass from destructive fishing gear, allowing seagrasses to grow undisturbed and re-colonise previously damaged areas of seafloor. However, this meadow abruptly stops at the edge of the island where water depth increases, reducing photosynthetic potential and allowing for increased access for trawling vessels. Increased vessel presence, alongside reduced density of Conservation and Anti-Trawling Structure allows for increased sedimentation and prevalence of silt dominated substrate, thus reducing the recovery potential of the meadow while introducing an edge effect. This meadow edge therefore indicates the effectiveness of successful seagrass conservation in the form of a deterring presence, deployment of Conservation and Anti-Trawling Structures and enforced zoning. Where these strategies are limited, seagrass presence is directly threatened.

The most abundant species observed throughout the Kep archipelago were *Thalassia hemprichii, Enhalus acoroides* and *Halophila ovalis*. This study is concurrent with previous studies on meadows across the South East Asia bioregion, finding *Thalassia hemprichii* a dominant species within meadows (Fortes *et al*., 2018; UNEP, 2008). *Enhalus acoroides* was found fringing the shallow coastal zone of Koh Tonsai, where sexual reproduction is achievable (Den Hartog, 1970). *Enhalus acoroides* was distributed in isolated patches across the Koh Poh and Koh Ach Seh meadows. Some of these patches were observed to be only a few meters in diameter. This patchiness of colonious fragments is not uncommon due *Enhalus'* rhizome branching and longevity of shoots (Marbà and Duarte, 1998; Vermaat *et al*., 2004). *Halophila ovalis* was distributed across each meadow, particularly toward meadow edges and degraded areas. It is well documented to be a pioneer, eurybiontic species, which is extremely tolerant to poor light levels, poor water quality, and unstable sediment (Den Hartog, 1970). The difference in structure and characteristics of the three most abundant species across the archipelago provide different ecological functions, and are therefore important in supporting a range of commercially valuable fisheries species (Gullström *et al*., 2008; Hori *et al*., 2009).

Observations of seagrass percentage cover and shoot density at each of the three meadows reflect the typical parabolic pattern of seagrass abundance with increasing depths, with low abundance towards shallower limits, increasing to maximal abundance around intermediate depth then declining exponentially thereafter (Duarte, 1991). Water shallower than one meter was located at Koh Tonsai, where *Thalassia hemprichii, Cymodocea serrulata, Enhalus acoroides* were most abundant. Koh Tonsai and Koh Ach Seh meadows had the highest abundance of seagrass at depths between 1 and 2m. Observations of Koh Poh were only found at depths deeper than 2m. Percentage cover and shoot density were also highest at this depth. The intensity and quality of light available for photosynthesis are the main factors regulating plant growth and development (Hemminga and Duarte, 2000; Kaewsrikhaw *et al*., 2016). The shallow waters throughout the archipelago provide unique marine conditions which should support extensive seagrass growth because, given suitable substrate for establishment, growth is constrained largely by depth limits (Duarte, 1991). The depth limits of each of the species observed in the Kep archipelago are reported to be around 10m (with the exception of *Halophila decipiens;* Duarte, 1991). However, due to increased siltation from bottom-trawling, seagrass species richness and leaf biomass sharply declines as silt substrate exceeds 15% (Terrados *et al.,* 1998; Palanques *et al.,*2001). As a result of habitat destruction and siltation, driven by bottom-trawling activities, the community dynamics of seagrass ecosystems are adversely affected, preventing the recovery and reconnection of the Kep archipelago meadow fragments (Freeman *et al*., 2008; Maciá and Robinson, 2005; Pillay *et al*., 2010; Short *et al*., 2011). It is also important to note that these meadow fragments are directly protected due to their positioning in shallow, inaccessible locations, limiting bottom-trawling activity and the resulting siltation.

Small, fast-growing species, such as *Halophila* spp., are considered pioneer species and often have the ability to form large, persistent seed banks (Inglis, 2000). Colonisation of degraded areas by *Halophila* species can facilitate the subsequent growth and colonisation of less tolerant, slow-growing species, such *Thalassia hemprichii,* and therefore, contribute towards meadow expansion and connectivity (Ooi *et al*., 2011). However, colonisation from seed banks (viable seeds within sediment (Orth *et al.,* 2007)) cannot be assumed as bottom-trawling decimates large areas of seafloor and actively growing seagrass, thus preventing the future potential for colonisation from seed dispersal and the persistence of seeds in the sediment (Lavery *et al.,* 2018). In the Kep archipelago, retention of all seagrass biomass is vital for future re-colonisation of denuded seafloor thorough rhizome elongation and seed dispersal from existing meadows. Therefore, the location and characteristics of the Kep archipelago meadows serve as a vital connective habitat between the Cambodian coastline, offshore islands and Vietnamese meadows. Safeguarding connectivity between these diverse seagrass habitats by reducing sediment disturbance, encouraging meadow re-growth, and limiting direct damage to plant biomass is necessary to build the resilience of regional marine ecosystems and the coastal communities which depend upon them (Unsworth *et al.,* 2015).

Foliage length was observed to increase down the depth gradient for both *Thalassia hemprichii* and *Halophila ovalis*. In conditions of diminishing light level, increased foliage surface area is advantageous to maximize photosynthetic capacity (Xu *et al.,* 2011; Enríquez *et al*., 2019). However, under these light-limited conditions seagrasses mobilise stored carbohydrates to maintain metabolic processes, resulting in reduced carbon fixation. Rhizome biomass is reduced under prolonged limited light as respiration becomes a burden on the plant. Therefore, seagrass species with a low total biomass are often found in deeper waters, largely because there is less plant material to maintain metabolically (Ralph *et al.,* 2007). In addition, the reduced rhizome biomass found in finer species, such as *Halophila* species, decreases the effectiveness of sediment stabilisation by the plant (Fonseca, 1989). Therefore, it is important to implement conservation strategies, such as Conservation and Anti-Trawling Structures, that conserve plant biomass, in turn stabilising sediment. The epiphytic algal cover on seagrass leaves in the Kep archipelago was also found to increase down the depth gradient. Epiphytic algae are prominent components of seagrass ecosystems, and play a key role in nutrient cycling and food provisioning for grazing species (Cornelisen and Thomas, 2002; Borowitzka *et al.,* 2007). However, anthropogenic disturbance, elevated nutrient input and reduced grazer activity increase epiphytic cover (Mabrouk *et al.,* 2013; Zhang *et* al., 2014; Whalen *et al.,* 2013). Excessive epiphytic-load impedes seagrass performance by negatively affecting the availability of oxygen to the plant and reduces the aeration capacity of the rhizosphere as a defense against plant toxins (Brodersen *et al.,* 2015). In the Kep archipelago, nutrient influx from estuarine sources and increased water turbidity from sediment resuspension from destructive fishing activities in deeper waters, are likely to accelerate epiphytic growth, reducing the resilience of seagrass meadows (Palanques *et al.* 2001; Brodersen *et al.,* 2015). Longitudinal monitoring of: leaf length, epiphytic algal cover and substrate composition act as indicators of water quality and levels of sedimentation; will provide useful information contributing towards effective management of the archipelago and its surrounding waters (Frankovich and Fourqurean, 1997; Van Katwijk *et al.,* 2011).

Observations of 16 trawling tracks were made within two of the three seagrass meadow fragments, despite the temporary nature of such tracks due to current, and water flow. Trawling and dredging cause direct physical damage to seagrass plants and reduce water quality, resulting in fragmented meadows with reduced resilience (Short *et al.,* 2011; Erftemeijer and Lewis, 2006; Unsworth *et al.,* 2015). Following large-scale seagrass loss, slow-growing species, such as *Thalassia hemprichii,* can take decades to recover, and have difficulty recolonising damaged areas due to their life-history traits and sensitivity to benthic and water conditions (Duarte, 1995; Erftemeijer and Lewis, 2006; Kuo, 1993). Seagrasses, particularly *Thalassia* species, are among the most effective ecosystems at sequestering atmospheric carbon. However, when damaged, seagrasses leak locked carbon from their tissues and surrounding sediment back into the atmosphere, and the capacity of the remaining meadows to sequester carbon is reduced. The continued declines of seagrass habitats, as a result of human disturbance, will likely have myriad ecological implications and globally significant economic and social consequences. This highlights a need for tailored seagrass and location-specific management strategies, such as Conservation and Anti-Trawling Structures and effective enforcement of legislation (Costanza *et al*., 1997; Heck *et al*., 2003; Hughes *et al*., 2009; Cullen-Unsworth *et al.,* 2014; Nordlund *et al*., 2018).

Recommendations and Future Research

This study aims to be the foundation for a national seagrass database for Cambodia. MCC aims to conduct future surveys along the Cambodian coastline to further contribute to the understanding of Cambodia's seagrass meadows.

This research provides a detailed description of seagrass abundance, diversity and extent in the Kep archipelago, highlighting seagrass hotspots, and areas which may require prioritised conservation action. This seascape scale understanding of the flora within the archipelago and MFMA can be used in longitudinal monitoring to assess changes in the state of the archipelagic seagrasses and used to inform management and policy. Future monitoring and exploration will use this baseline data to assess incidences of damage or successful re-establishment of seagrasses within the archipelago, thus highlighting the resilience and ecological importance of seagrass.

This baseline of seagrass extent and diversity directly informs sediment and seagrass sampling required to investigate the carbon sequestering potential of the Kep archipelago. Along with expanding seagrass surveys along Cambodian coastline, surveys to measure distribution, abundance, extent and composition of seagrass will allow for an estimation of Cambodia's seagrass carbon sequestration potential, giving economic value to an otherwise compromised marine resource.

Future ecological and social research, twinned with schools and community outreach, will contribute towards raising the profile of the Kep archipelago. Offering these information-based resources to local inhabitants and marine resource managers, will aid the sustainable use of seagrass meadows and their associated fauna. Advocated sustainability will encourage vital community-based conservation of ecologically and socio-economically important seagrass meadows.

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