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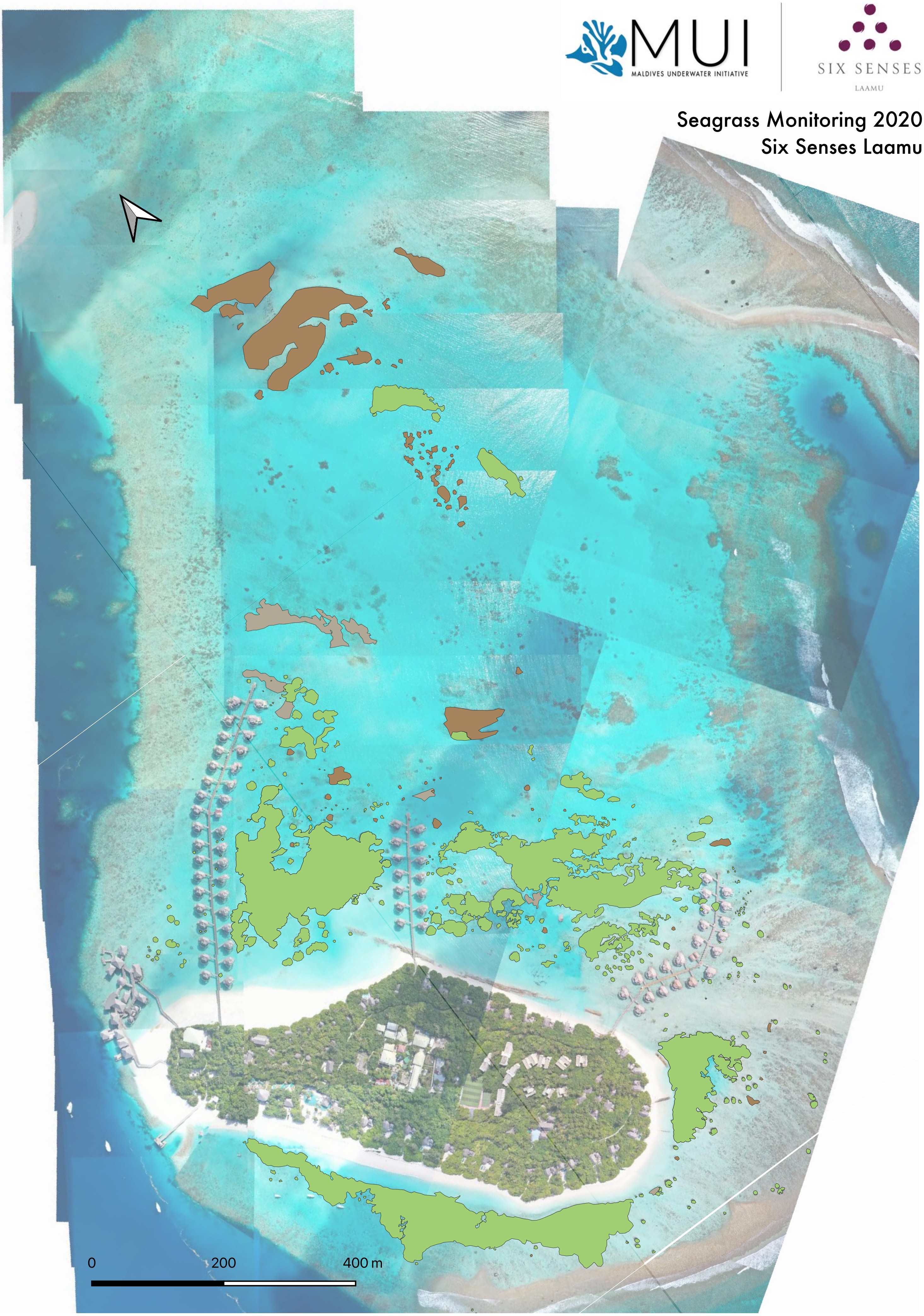
SIX SENSES
LAAMU

Seagrass Monitoring 2020
Six Senses Laamu



Six Senses Laamu Seagrass Monitoring 2020

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Executive summary

In response to out-dated and scarce information regarding seagrass meadows in Maldives, the Maldives Underwater Initiative (MUI) and Blue Marine Foundation launched the Maldives National Seagrass Monitoring Network (MNSMN). This protocol for monitoring seagrass meadows has been accepted by Maldives Marine Research Institute (Ministry of Fisheries and Agriculture) as a standard monitoring protocol at national level. The present study is the second consecutive year using this protocol to survey the lagoon of Olhuveli Island, Laamu Atoll, as the beginning of a long-term monitoring project. A total area of 116,695 m2 of seagrass was calculated, a 20% increase over 12 months. The lagoon was split into different sections for analysis. The section with the highest percentage increase was AD (611%). Sections AB (75% increase) and BC (48% increase) have both grown to merge several smaller patches, now forming large continuous meadows. The area with the smallest increase was OW (0.3%), likely due to its location within a narrow strip sandwiched between beach and reef, facing higher wave energy and with little room for expansion. In total, five species of seagrass were observed, this was one less than the previous year. The sixth species found in 2019 was only in a very small quantity in one location amongst other species. The species composition was highly varied within lagoon sections and between lagoon sections. The most similar in composition were AB, BC and OW, the most unique were OS and SB. The spatial variation within meadows, and different sampling methods between 2019 and 2020 meant that change in species composition over time cannot be accurately compared. The 2020 data collected was extremely thorough, with over 400 data points. This study provides a detailed baseline for monitoring going forward, which encompasses the whole lagoon platform and can provide a historic reference to investigate long term trends. With this standardised method, the data can be further explored to investigate ecosystem functions and can also be compared nationwide, providing the basis for the Maldives first ever national seagrass monitoring program.

Background

Although ecologically important, seagrass meadows are globally under threat from both direct and indirect human influences (such as dredging, coastal development and impacts of climate change). It is predicted that the loss of these habitats will accelerate, particularly in South-East Asia, due to increased coastal development (Daurte, 2002). Positive human impacts, such as changes to legislation protecting seagrass meadows, may help slow this, however it has been suggested that this is unlikely to be implemented and managed effectively in tropical regions, where capacity and resources are limited (Daurte, 2002).

In Maldives, information about the status of seagrass meadows is scarce and out-dated. Only three peer reviewed papers have been published regarding seagrass in Maldives, and only one in the last 8 years (Miller and Sulka, 1999; Claude et al., 2012; Rotini *et al.*, 2019). Within these publications, only three species of seagrass are described to be found in Maldives, a figure that was also stated in a more recent global report (UNEP, 2020). However, surveys by the Maldives Underwater Initiative (MUI) at Six Senses Laamu found six species in Laamu atoll in 2019 (MUI, 2019), and an additional two had been discovered elsewhere in Maldives in 2020 (photographic confirmation). This out-dated information illustrates lack of knowledge available about these key habitats. Furthermore, seagrass meadows in Maldives have commonly been perceived as a nuisance rather than of ecological value. Many tourist resorts actively removed seagrass due to this perception, having marketed clear white sand lagoons, based upon the principal that tourists would think seagrass is ugly or dirty (MUI, 2019). In order to effectively implement and manage regulations to prevent further loss of these key habitats, it is vital to gain current understanding. In response, a social media campaign (#ProtectMadivesSeagrass) was launched in 2019 by MUI and Blue Marine Foundation, which resulted in over 900,000 m2 of seagrass meadows, mostly surrounding resort islands, protected under voluntary pledge. Following this, the Maldives National Seagrass Monitoring Network protocol (MNSMN) was launched in January 2020 in collaboration with James Cook University and Murdoch University, and was accepted by the Ministry of Fisheries and Agriculture as a standardised monitoring method in March 2020. This protocol is the first step in a nationwide assessment and monitoring of seagrass meadows.

Seagrass meadows are often dynamic in their size, density or composition due to a heavy reliance on environmental conditions to sustain their viability (Daurte *et al.*, 2007). How a meadow changes over time can affect the ecosystem functions the meadow supports, such as providing habitat (Gullström *et al.* 2008; Horinouchi, 2008; Jackson et al.,2001), as a food source (Thayer, 1984) and stabilising the seabed (Gordon, 1986). Therefore, to understand the value and importance of seagrass meadows in Maldives, they must be studied over many years. The seagrass meadows surrounding Olhuveli Island, the location of Six Senses Laamu resort, have been protected under pledge since 2018, having previously been removed. The first in-depth study of these meadows was completed in April 2019, establishing a baseline for annual monitoring. Continued monitoring of these meadows aims to reveal the changes over time both in size and composition, in addition to processes supported by the meadows, such as fish production, carbon sequestration or as a food source for green turtles (*Chelonia mydas)*. In 2019, monitoring level two of MNSMN was used, in addition to mapping the meadow boundaries (MNSMN, 2020). The total area of seagrass was 93,961m^2 and six species of seagrass were reported; *Thalassia hemprichii (Th)*, *Thalasadendron ciliatum (Tc), Halodule pinofilia (Hp), Syringodium isoetifolium (Si), Cymodocea rotundata (Cr)* and *Halophila ovalis (Ho).* Four distinct areas of seagrass were identified within the lagoon, each found to have different species composition, with the meadows between jetties A and B (AB) and Olhuveli South (OS) being the most different in composition, having no species in common. The most diverse meadow was Olhuveli West (OW) containing all six species and the least diverse was OS, containing only two species. OW was also the largest meadow (29,885m^2), whilst OS was the smallest (8,967m^2) (Figure 1).

For the second year of monitoring, this report aims to describe changes in the meadow species composition, extent and density 12 months on from the previous study, and more than three years since discontinuing the practice of seagrass removal in the area. The 2019 surveys were conducted using monitoring level two, whereas the 2020 surveys were conducted using monitoring level three (MUI, 2019; MNSMN, 2020; See appendix 1). Both protocols use the same method of data collection, but the sampling method varies. This report will serve as an example of meadow monitoring using the newly established national monitoring methods and illustrate the compatibility between levels of monitoring outlined in the national monitoring protocol, that can be used nation-wide with varying levels of capacity.

Methods

Survey method

The survey methods used are as outlined in the Maldives National Seagrass Monitoring Network protocol (MNSMN, 2020), monitoring level three, and implemented as described below. Surveys were conducted between 17th April and 1st May 2020.

A composite drone photo was created of the island lagoon and surveys logistics were determined by lagoon sections. These sections were defined as areas of clear separation by over water jetties (AB, BC and AD), on different side of the island (OS and OW) or the area between the end of a jetty and the sand bank to the north (SB) (Figure 1). Teams of two travelled in rough parallel lines within a lagoon section using visual markers. Throughout the meadows, a 50 by 50 cm quadrat was placed within areas of seagrass, spaced at least 20 kick cycles apart. Within smaller patches, quadrats were randomly placed within the patch with number of replicates depending on size of the seagrass area. The GPS waypoint of each quadrat was recorded (using a Garmin Etrex 10), and care was taken to note meadow boundaries, as well as recording areas of reef, rubble, macroalgae or any substrate that could be mistaken for seagrass on the drone images. The lagoon was surveyed thoroughly totalling 401 data points.

Meadow extent

The meadow extent was calculated by overlaying all datapoints with the geo-referenced composite drone photograph (using QGIS version 3.10.3-A Coruña), and tracing all areas confirmed to be seagrass. Areas of reef and rubble were also marked for future reference. As the 2020 surveys were more thorough than the previous year, outlying areas of seagrass visible on both the geo-referenced 2019 and 2020 drone images, but not previously included, were incorporated into a revised measurement of the total seagrass area in 2019. This amounted to an additional 3306 m^2 of seagrass, amending the 2019 total meadow extent to 97,267 m^2. Percentage increase of seagrass area from 2019 to 2020 was then calculated for each lagoon section.

Species composition and density

Species composition and percentage cover within the main lagoon areas (AB, BC, OS and OW) was determined, in addition to developing areas (AD and SB). Proportionate pie-charts were overlaid on a map of the meadow boundaries showing the percentage species composition and density. Change in species composition for each lagoon area between years was investigated using a non-metric multi-dimensional scaling plot (using RStudio version 1.1.419), sites were displayed with direction arrows indicating each lagoon area over time.

Canopy height, algae and epiphyte cover

Mean canopy height for particular species was determined using data points consisting of a single species. Mean epiphyte load was calculated by replacing ‘none’, ‘low’, ‘medium’ and ‘high’ with the values 0, 1, 2 and 3 respectively, and was calculated alongside mean algae cover for each lagoon section. Variance was calculated as standard error.

Results

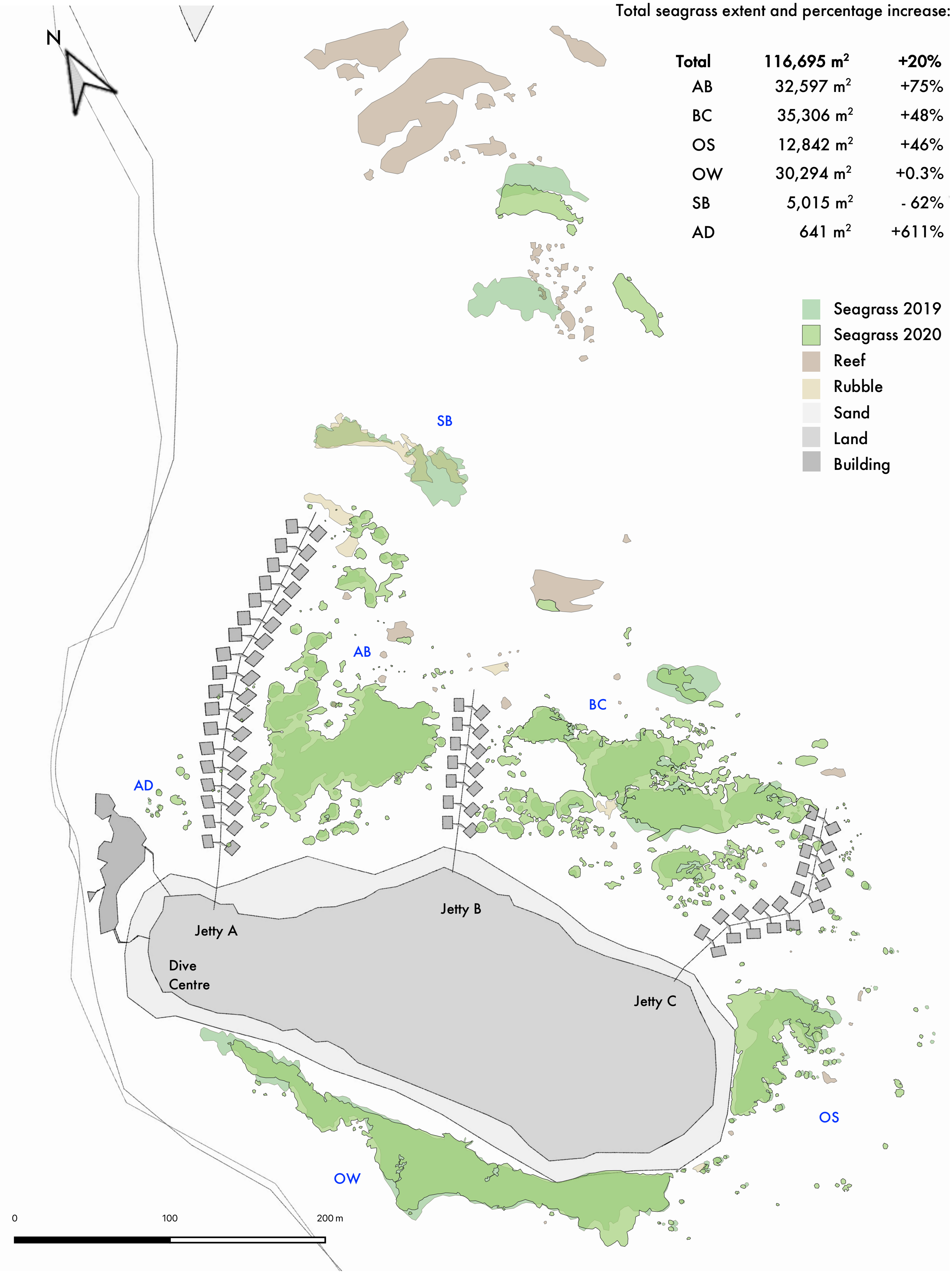


Figure 1. Total extent of seagrass, along with significant areas of reef and rubble within the lagoon of Olhuveli Island, April 2019 and 2020. Lagoon sections labelled in blue are defined as all seagrass within that area of clear separation, by over water jetties (AB, BC and AD), on different side of the island (OS and OW) or the area between the end of jetty A and a sand bank to the north (SB).

Meadow Extent

The total area of seagrass cover in 2020 was 116,695 m^2, a 20% increase since 2019. The lagoon section with the largest total area of seagrass was OW with 30,294 m^2, a 0.3% increase since 2019. This is followed by BC (35,306 m^2) and AB (32,597 m^2), 48% and 75% increase respectively. The section with the smallest area of seagrass was OS (12,842 m^2) that had increased by 46%, in addition to peripheral areas that were recorded, SB (5015 m^2) and AD (641 m^2), that had decreased by 61% and increased by 611% respectively (Table 1, Figure 1).

The largest continuous meadow was OW totalling 29,814 m^2, followed by AB (26,904 m^2) and BC (22,2002 m^2). Both meadows AB and BC now encompass multiple patches that were recorded as separate in 2019. Meadow AB has merged 13 individual patches and BC has merged 8. OS was the smallest continuous meadow of the 4 identified sections at 11,250 m^2 (Table 1, Figure 1).

Table 1. Total extent of seagrass at Olhuveli Island by lagoon section between April 2019 and 2020, in order of total area in 2020.

Lagoon Section	2019 (m^2)	2020 (m^2)	Increase (m^2)	Increase (%)
OW	30,200	30,294	95	0.3
BC	23,924	35,306	11,382	48
AB	18,611	32,597	13,986	75
OS	8,786	12,842	4,056	46
SB	13,062	5,015	-8,048	-62
AD	90	641	551	611

Total species composition

In 2020 a total of five seagrass species were observed throughout the lagoon; *Thalassia hemprichii (Th), Thalasadendron ciliatum (Tc), Halodule pinofilia (Hp), Syringodium isoetifolium (Si), Cymodocea rotundata (Cr)*. Despite extensive searching, *Halophila ovalis (Ho)*, observed in 2019, was not present.

The lagoon sections most similar in species composition were AB, BC and OW, containing all five species recorded (Figure 2, 3). This was also the case in 2019, however these three sections have increased in similarity in composition since 2020 (Figure 2). Sections OS and SB contained only two species in each section, with no species in common (Figure 3).

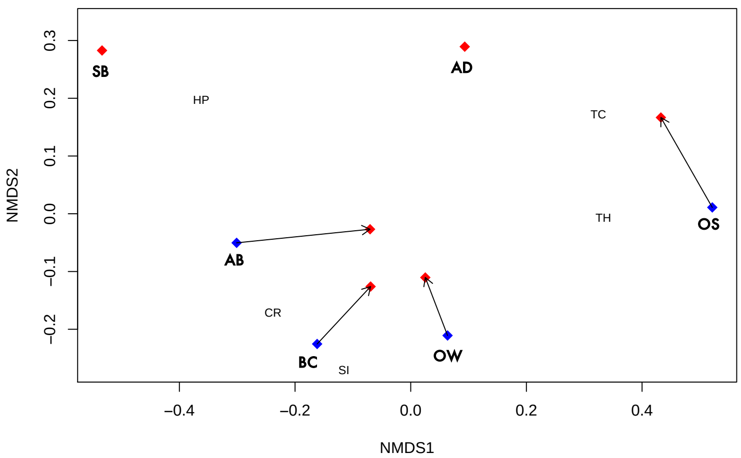


Figure 2. Non-metric multi-dimensional scaling plot of seagrass species composition at six areas within the lagoon of Olhuveli Island, Laamu Atoll, Maldives. Labels in bold indicate site codes, labels in regular font indicate species codes. Blue and red squares indicate data from 2019 and 2020, respectively. Arrows indicate directional change in species composition between years.

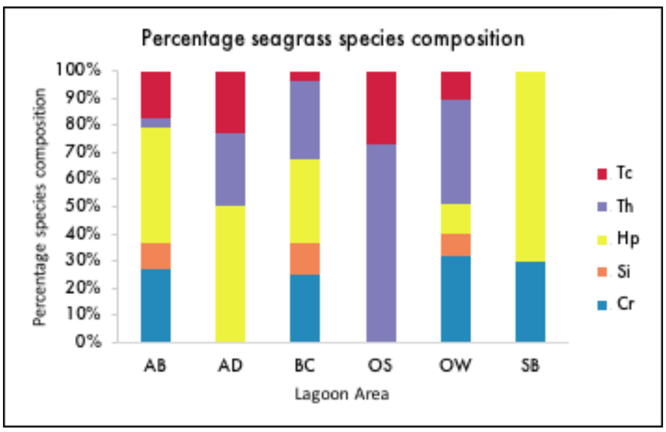


Figure 3. Percentage species composition of seagrass in areas of Olhuveli Island lagoon. Species codes: *Thalasadendron ciliatum (Tc), Thalassia hemprichii (Th), Halodule pinofilia (Hp), Syringodium isoetifolium (Si), Cymodocea rotundata (Cr).*

Spatial variance in species composition and density

Sections AB and BC show a high spatial variation in species composition. Both consist of *Hp* as a dominant species within the main continuous meadow, in addition to *Si* and *Cr* primarily towards the boundary. However surrounding smaller patches within AB consist mostly of highly dense *Tc* (mean 90% cover) and less dense *Cr* (mean 56% cover) (Figure 4a, 4b), and the surrounding smaller patches within BC consist of *Cr* (mean 62% cover) is most dominant to the west side, and *Th* (mean 55% cover) to the east (Figure 4b). OW has areas of low density in comparison to the other meadows, and also high spatial variability in species composition. The southern end consists mainly of *Tc* and *Th*, whereas the northern end is a mixture of all species (Figure 4d). The main continuous meadow in section OS consistently comprises of *Th* (mean 69% cover), with surrounding patches of *Tc* (mean 100% cover) (Figure 4c).

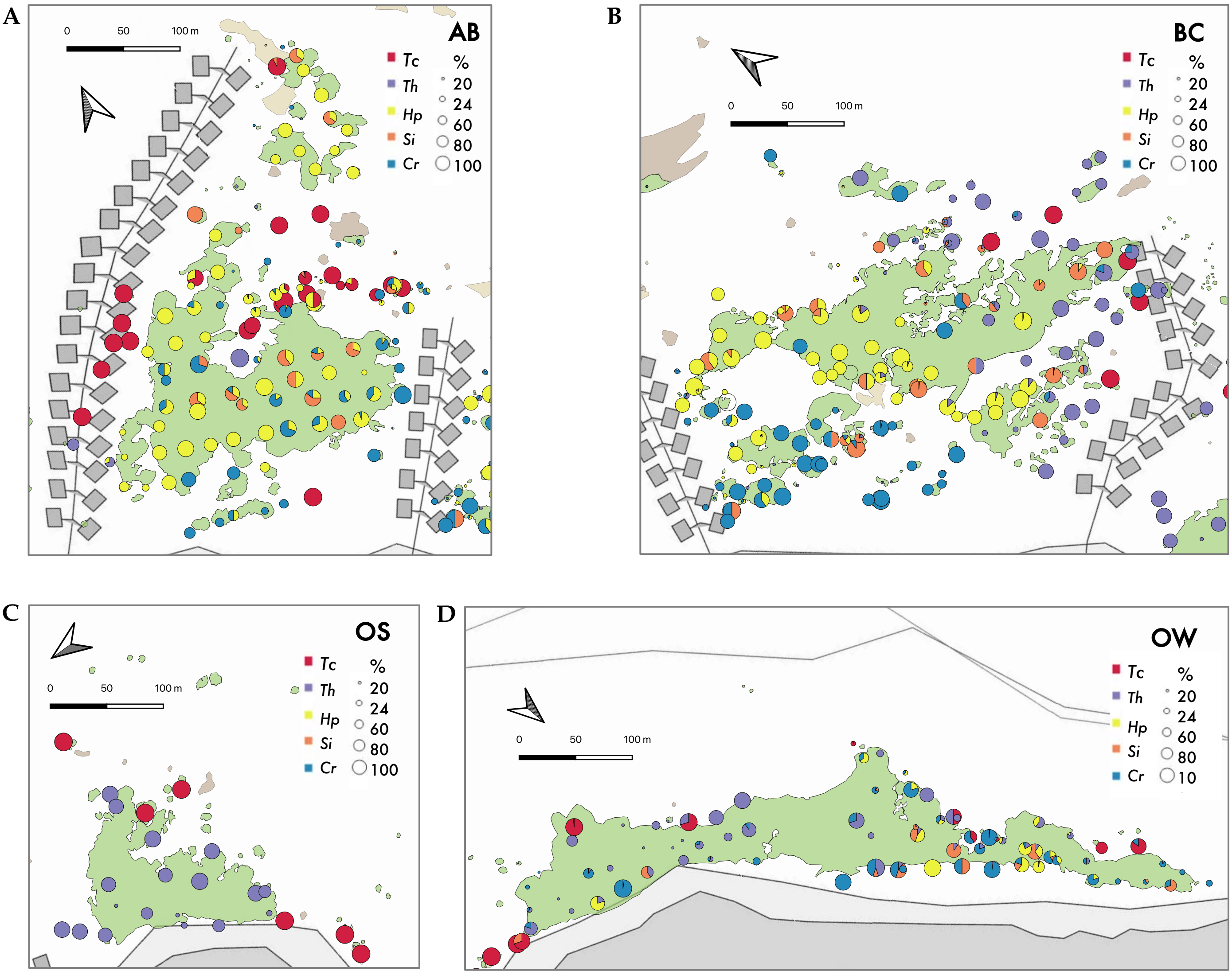


Figure 4. Species composition and density (percentage cover) spatial distribution of seagrass within of four main identified sections of Olhuveli Island lagoon, Laamu Atoll, Maldives. Pie charts indicate species composition and proportionate chart size represents density at each data point.

Mean algae cover, epiphyte load and species canopy height

Mean algae cover within seagrass across all lagoon sections was 27.7% (±SE 1.4). The lagoon section with the highest percentage algae cover was AB with 35.4% (±SE 3.1), followed by SB with 33.1% (±SE 11.7) and BC with 29.9% (±SE 2.3). The lagoon section with the lowest algae cover was AD with 2.3% (±SE 0.8) followed by OS with 5.2% (±SE 1) and OW with 20.3% (±SE 2.3).

Mean epiphyte load across all lagoon sections was 1.8 (±SE 0.1). The section with the highest epiphyte load was SB with 2.4 (±SE 0.8), followed by AB with 2.0 (±SE 0.2), OW with 1.9 (±SE 0.2), OS with 1.7 (±SE 0.3) and BC with 1.6 (±SE 0.1). The area with the lowest epiphyte load was AD with 1.3 (±SE 0.5).

The species with the tallest canopy was *Tc* with a mean of 26.1 cm (±SE 1.5), followed by *Si* with 8.8 cm (±SE 1.7) and *Cr* with 7.3 cm (±SE 0.3). The species with the shortest mean canopy height was *Th* with 4.4 cm (±SE 0.2) followed by *Hp* with 6.0 cm (±SE 0.3).

Discussion

Meadow extent

A total area increase of 20% in 12 months illustrates the rapid expansion of seagrass meadows within the lagoon. Successful rhizome extension or the seeding of new recruits increases the footprint seagrass meadows (Daurte *et al.*, 2007). Throughout the meadows, new small areas were observed spreading from a single point, as well as to established patches expanding and merging. This suggests that both processes are in action, and environmental conditions are suitable to allow them to do so. A rapid expansion in meadow extent within sections AB and BC could be explained by their species composition, consisting of fast growing species such as *Cr* and *Si*, which are more likely to show significant changes over shorter timescales such as one year (Daurte *et al.*, 2007, Middleton *et al.*, 1984). Furthermore, *Syringodium isoetifolium* was observed in flower throughout sections AB and BC, illustrating its fecundity within these areas.

Section SB showed a 62% decline in seagrass area since 2019, due to the disappearance of a large patch where mostly rubble and reef was recorded in 2020. Further investigation of photographs from 2019 and 2020 in addition to reviewing the 2019 ground truth information allows for speculation that either the seagrass location was mis recorded in 2019, or the area consisted of very low-density cover, which did not survive as a sandy substrate transitioned to predominantly rubble.

Section OW showed very little expansion (0.3%). This section is a narrow strip, sandwiched between the beach and reef. The meadow occupies the majority of the area continuously with little room for expansion. It is therefore expected that in comparison to the other sections, OW would show little expansion in footprint, due to lack of suitable substrate. Section OW was also the least dense in seagrass cover. Due to its proximity to the reef crest, this section is exposed to higher wave energy, which can influence both the substrate type, the turnover of new shoots and seagrass density, providing less desirable conditions for growth (Daurte *et al.*, 2007, Paling, *et al.*, 2003).

Species composition

In comparison to 2019, one less species was found within the lagoon, with *Ho* being absent. In 2019 this species was only observed during ground truthing (not during surveys) and was found only in a very small area covered (less than 1 m^2), amongst other species, at the north of section OW. With such a small footprint, it is possible that this species could not outcompete the others, however it is found as the only species in larger meadows at nearby islands. Due to this, there is potential if the lagoon conditions are suitable, that *Ho* may be found in future monitoring surveys of Olhuveli lagoon.

There was significant spatial variation in species composition between lagoon sections and within lagoon sections. Section OS was the only area with a relatively uniform meadow, consisting of *Th* with surrounding patches of *Tc*. This section was the most unique in composition in comparison to the other main lagoon sections. The main meadow within section AB consists predominantly of *Hp*, with areas of *Si* and *Cr*. However, the surrounding smaller patches consist mostly of dense *Tc*. The western area of section BC consists mostly of *Cr*, whereas within the central section *Hp* is dominant, and to the east *Tc* and *Th* are the most prominent. This spatial variation highlights the limitation of the 2019 data in characterising species composition of the meadow and is unlikely to be representative due to high spatial variability. Incorporating the whole lagoon section, as in 2020, areas AB, BC and OW become more similar in species composition due to the inclusion of all periphery patches (See Appendix). Therefore, species composition change between the two years must be viewed in consideration of this. An alternative method would have been to take a sub-sample of the 2020 data points that fell within the 2019 sampling area. However, this would only give change in composition within a small area, rather than how the meadows are transforming over time. Therefore, it might be necessary that 2020 become the baseline for comparison with future monitoring when considering these variables.

Mean algae cover, epiphyte load and species canopy height

Algae cover was more varied between lagoon sections in comparison to 2019. AB and BC exhibited higher algal cover in 2020, whereas OS and OW exhibited much lower. This is likely due to the spatial distribution of the data points. Algae cover (particularly drift algae) can be influenced by water movement, meaning the 2019 data points within the main continuous meadows are likely to show different results to those at more exposed edges incorporating all peripheral patches and differing species composition. Incorporating all peripheral points of OS and OW includes those areas that are close to the exposed reef edge, and therefore are less likely to contain drift algae. Both epiphyte and algae cover are likely to vary seasonally due to changing sea temperature, turbidity and prevailing wind direction. Therefore, it would be beneficial to conduct monitoring bi-annually to determine any seasonal differences.

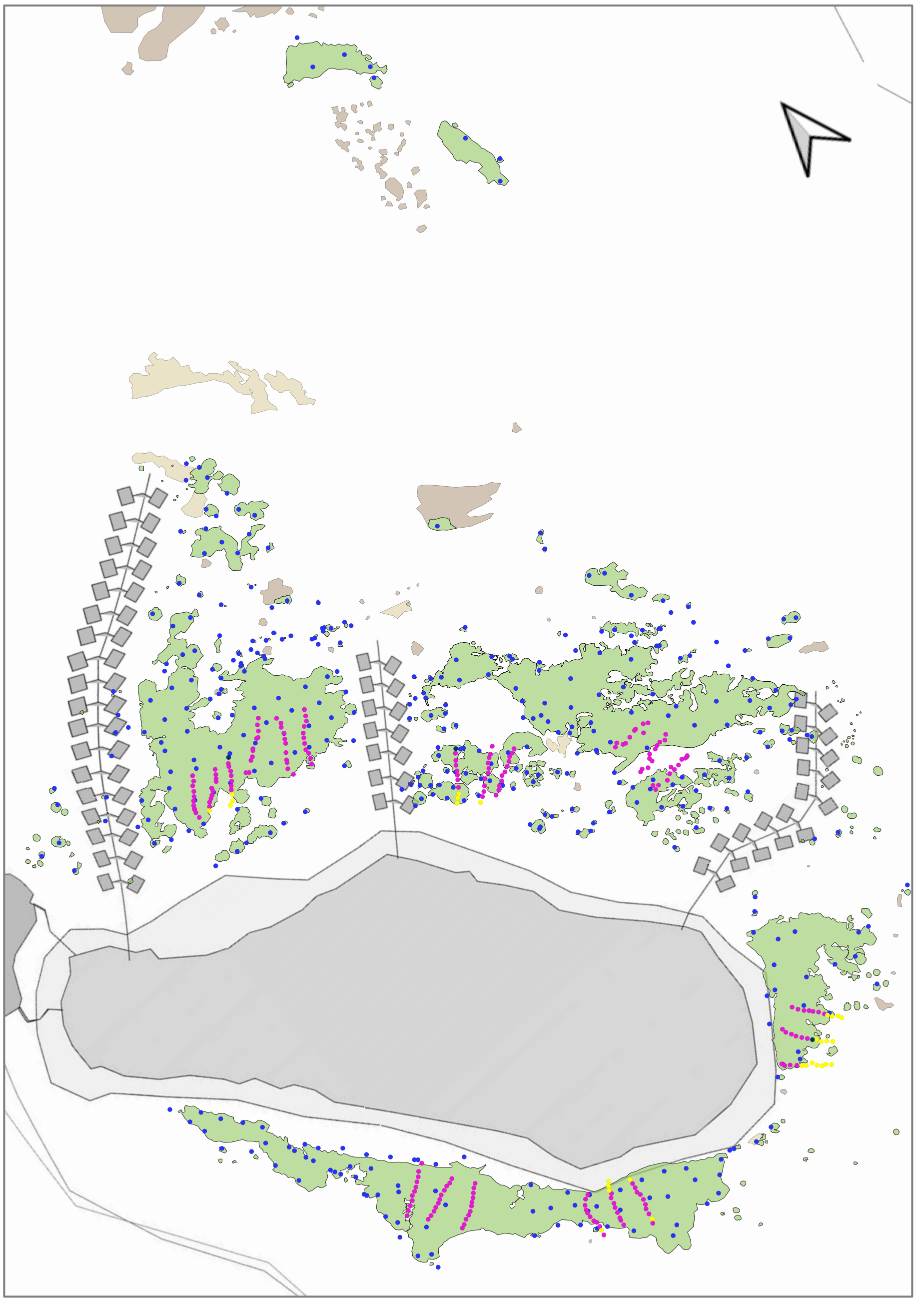
It is well recognised that the structure and biomass of seagrass plants vary hugely between species, and therefore support different ecosystem functions. Although not covered in this study, in the future it would be useful to also quantify fish abundance, sediment accretion or evidence of grazing, to start to piece together the true value of seagrass meadows in Maldives. For example, in the present study, *Tc* had a mean canopy height of 26.1 cm, which is a large volume of habitat for juvenile and adult fish to use as protection. Quantifying this would help to understand influences different seagrass species or meadow characteristics have on ecosystem services.

Conclusions
This study is the beginning of long-term monitoring of the seagrass meadows within the lagoon of Olhuveli island. The meadow extent shows large expansion in just 12 months, with both new and merged areas, suggesting areas AB, BC and OS are thriving, in addition to peripheral areas such as AD are developing away from the main meadows. The spatial variability of the meadows demonstrates how these diverse habitats are not uniform, and furthermore are likely to change over time. Key future observations will be to monitor the stability of OW, with little room for expansion and low percentage cover, and to observe how species composition changes within AB and BC as multiple patches merge. Alongside this is will be important to quantify ecosystem services supported by the seagrass meadows, and how these change as the meadows develop, particularly fish production, in relation to species composition, canopy height and lagoon section.

This report has demonstrated that differing levels of MNSMN protocol are compatible, however care must be taken when drawing comparisons between data with differing sampling spatial distribution. With standardised methods, these results will be comparable over time and also between locations across the country building a better knowledge base of this habitat with the Maldives.

Appendix

Data points 2019 and 2020. Blue points indicate 2020 data points, pink points indicate 2019 data points with seagrass, yellow indicates 2019 data points with 0% cover seagrass. Seagrass meadow outline is area from 2020.



References

Claude E. P., Antoine D.R. N, Lydiane M., (2012). Benthic Algal and seagrass communities in Baa atoll, Maldives, Institut de Recherche pour le Développement, BPA5, Nouméa, New Caledonia

Duarte, C.M., 2002. The future of seagrass meadows. *Environmental conservation*, pp.192-206.

Duarte C.M., Fourqurean J.W., Krause-Jensen D., Olesen B. (2007) Dynamics of Seagrass Stability and Change. In: Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht

Gordon, D. M. (1986). *Marine Communities of the Cape Person, Shoalwater Bay and Warnbro Sound Region, Western Australia.* Department of Conservation and Environment, Marine Impact Branch. Perth, Western Australia.

Horinouchi, M. (2008). *Horizontal gradient in fish assemblage structures in and around a seagrass habitat: some implications for seagrass habitat conservation*. *Ichthyological Research* 56(2): 109-125.

Jackson et al. (2001). *The importance of seagrass beds as a habitat for fishery species.* Oceanography and Marine Biology. 2001; 39:269-303

Maldives Seagrass Monitoring Network. Monitoring Methods. V1.1 (2020). See:
http://maldivesresilientreefs.com/resources/ MaldivesSeagrassMonitoringMethods.pdf

Middleton, M.J., Bell, J.D., Burchmore, J.J., Pollard, D.A. and Pease, B.C., 1984. Structural differences in the fish communities of Zostera capricorni and Posidonia australis seagrass meadows in Botany Bay, New South Wales. *Aquatic Botany*, *18*(1-2), pp.89-109.

Miller, M.W. and Sluka, R.D., (1999) Patterns of seagrass and sediment nutrient distribution suggest anthropogenic enrichment in Laamu Atoll, Republic of Maldives. *Marine Pollution Bulletin*, *38*(12), pp.1152-1156.

MUI- Shareef, Wu, Roe (2019) MUI Seagrass Monitoring Report April 2019: *Characterizing and establishing baselines for Seagrass Meadows at Olhuveli Island, Six Senses Laamu.*

Paling, E.I., Van Keulen, M., Wheeler, K.D., Phillips, J. and Dyhrberg, R., 2003. Influence of spacing on mechanically transplanted seagrass survival in a high wave energy regime. *Restoration Ecology*, *11*(1), pp.56-61.

Rotini, A., Conte, C., Seveso, D., Montano, S., Galli, P., Vai, M., Migliore, L. and Mejia, A., 2020. Daily variation of the associated microbial community and the Hsp60 expression in the Maldivian seagrass Thalassia hemprichii. *Journal of Sea Research*, *156*, p.101835.

Thayer, G.W., Bjorndal, K.A., Ogden, J.C. *et al.* Role of larger herbivores in seagrass communities. *Estuaries* **7,** 351–376 (1984). https://doi.org/10.2307/1351619

United Nations Environment Programme (2020). Out of the blue: The value of seagrasses to the environment and to people. UNEP, Nairobi.