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Spatial Distribution and Quantitative Assessment of Seagrass Meadows in the Marine National Park and Sanctuary, Gujarat, India

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Abstract:

The present study assessed the spatial distribution and quantitative attributes of seagrass meadows in the Marine National Park and Sanctuary (MNP&S), Gujarat, using remote sensing, GIS and field-based quadrat sampling during February–March 2025. LISS-IV imagery (5.8 m spatial resolution) was used to delineate seagrass distribution, followed by field verification. A total of 103 quadrats were sampled across five islands to assess species composition, leaf-pair density, abundance, frequency, relative composition and canopy cover. Three species, *Halophila ovalis*, *Halodule uninervis* and *Halophila beccarii*, were recorded. The mapped seagrass extent was 787.80 ha (7.88 km²), with the largest extent occurring in the Bhaider–Noru–Chank–Mitha-Khara Chusna–Tam Reef group (503.22 ha). *Halophila ovalis* was the most widespread species, occurring at all five sampled islands. Its highest leaf-pair density was recorded at Narara (499.33 leaf pairs m^{-2}), while maximum canopy cover was recorded at Dhani (21.85%). *Halophila beccarii*, a Vulnerable species, was restricted to Dedeka-Mundeka, Dhani and Pirotan. The present assessment provides a contemporary baseline for seagrass distribution and species-level ecological attributes in the MNP&S. Differences from earlier estimates indicate the need for standardized, repeatable monitoring before temporal decline can be conclusively established.

Keywords: Seagrass; spatial distribution; GIS; remote sensing; *Halophila beccarii*; Marine National Park; Gulf of Kachchh

Introduction:

Seagrasses are submerged monocotyledonous flowering plants adapted to complete their life cycle in seawater and occur mainly in shallow coastal waters on all continents except Antarctica (Garrard and Beaumont 2014). They are rhizomatous plants with horizontally growing underground stems bearing nodes and internodes, from which leaves emerge(Marbà Núria 2004). Interconnected plants form seagrass meadows that range from small patches to extensive continuous meadows and may be monospecific or multispecies assemblages(Unsworth et al. 2022; Unsworth and Cullen-Unsworth 2017). Seagrass meadows are highly productive marine ecosystems with important ecological, economic and social functions(Cullen-Unsworth et al. 2014; Duarte 1999; Gullström et al. 2002). They provide primary production, fisheries and nursery grounds, habitat for vertebrates and invertebrates, carbon sequestration and coastal protection(Dunic et al. 2021; Larkum et al. 2006; McKenzie et al. 2020). Their roots and rhizomes stabilize sediments and reduce erosion, while nutrient uptake contributes to nutrient retention and water-quality regulation (Hemminga and Duarte 2000; Koch et al. 2006). Seagrass meadows also support threatened and ecologically important fauna, including dugongs, marine turtles, seahorses and numerous fish and invertebrate species(Green and Short 2003; Kamboj R.D. 2014; Larkum et al. 2006).

Seagrasses are sensitive to environmental and anthropogenic pressures. Climate-related changes, including increasing water temperature, turbidity and changes in light availability and salinity, together with extreme events, can affect seagrass distribution, structure and ecosystem functioning (Björk et al. 2008; Hyndes et al. 2016; Zhang et al. 2023). In India, seagrass meadows are affected by coastal development, commercial and recreational activities, fishing, aquaculture and agricultural runoff, shell harvesting and seaweed cultivation, as well as cyclones, storms, coastal uplift, herbivory and disease (Ramesh et al. 2019). In the Gulf of Kachchh, industrial

and domestic pollution, port development, sedimentation, solid waste, fishing and boating activities have been identified as potential pressures on seagrass meadows(Kamboj R.D. 2014).

Globally, seagrass meadows have experienced substantial losses and degradation, with reported declines of approximately 30–60% in some assessments (Evans et al. 2018; Valdez et al. 2020). These changes highlight the need for site-specific assessment and standardized monitoring to document present distribution and support conservation planning. The present study therefore assesses the current spatial distribution and ecological attributes of seagrass meadows in the Marine National Park and Sanctuary (MNP&S), Jamnagar.

Materials and Methods:

Study area: The study was conducted in the Marine National Park and Sanctuary (MNP&S), Jamnagar, Gujarat, India, along the southern coast of the Gulf of Kachchh. The MNP&S comprises a network of approximately 42 islands and associated intertidal and shallow marine environments. Quantitative seagrass assessment was conducted at Narara, Pirotan, Kalubhar, Dedeka-Mundeka and Dhani islands, located around Narara within the Gulf of Kachchh (Image 1).

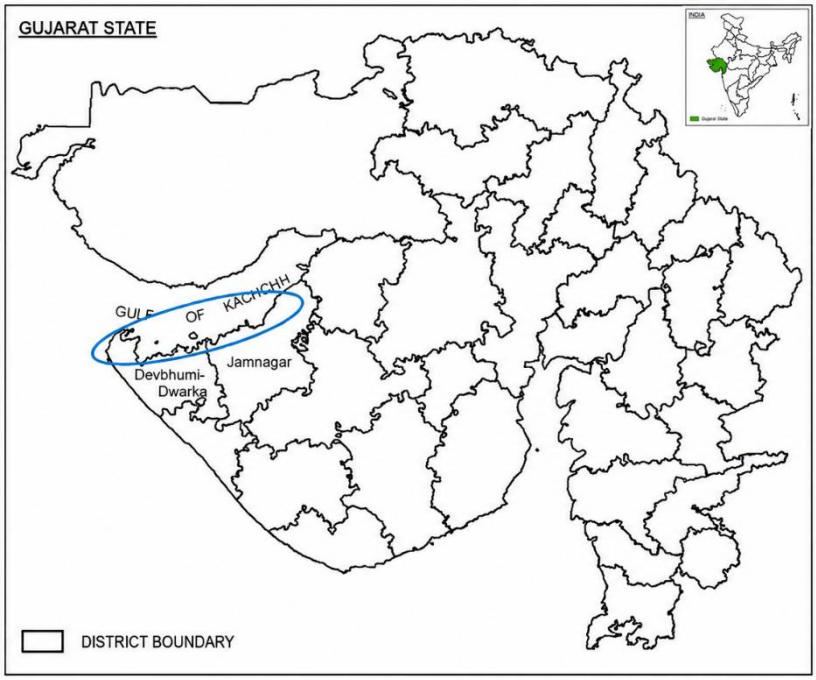

Image 1: Location map of the Study area

Field survey and species identification: Field surveys were conducted during February–March 2025 during suitable low-tide periods. A reconnaissance survey was undertaken to identify representative seagrass patches and select sampling locations. Representative specimens were collected for taxonomic verification and identified using standard taxonomic literature (Larkum et al. 2006; Pande 2021; Ramamuthy 1992). Quantitative assessment was conducted using randomly distributed quadrats within representative seagrass patches. A 1 m × 1 m quadrat (103) was used for density assessment, while a 50 cm × 20 cm Daubenmire quadrat (515) was used to estimate canopy cover. A total of 618 quadrats were sampled across the five islands.

Assessment of spatial distribution: The spatial distribution of seagrass meadows was assessed using LISS-IV satellite imagery (5.8 m spatial resolution) acquired for 2025, remote sensing and GIS techniques. Image processing and classification were undertaken using ERDAS Imagine. Seagrass patches were delineated using supervised classification based on representative samples derived from known seagrass locations. NDVI was generated as a supplementary layer to support identification and interpretation of vegetated areas.

The classified outputs were visually examined and refined using field observations for verification. The final classification was integrated into a GIS environment, and the mapped area of seagrass was calculated for individual islands and reef systems. The resulting spatial layers were used to characterize the distribution and mapped extent of seagrass within the study area.

Shoot density: A 1 m × 1 m quadrat was used to quantify seagrass density. Each quadrat was subdivided into 100 equal sections using nylon string to facilitate counting. A total of 103 quadrats were sampled across the five islands. Quadrats were distributed within representative seagrass patches to capture variation in meadow structure and density and were sampled during suitable low-tide conditions. The data were analysed in Excel; various ecological attributes such as density, frequency, abundance, and species composition were calculated using standard methods (Curtis and McIntosh, 1950).

Canopy cover: Seagrass canopy cover was estimated by the Daubenmire quadrat method (Daubenmire 1959) using a 50 cm × 20 cm quadrat frame positioned at the same locations as the 1 m × 1 m density quadrats. There were five Daubenmire quadrats laid at each location where one 1 m × 1 m quadrat was laid. Canopy cover was visually estimated for each species using six predefined cover classes (Table 1). The midpoint of each class was used as the representative percentage value for calculating mean canopy cover. Seagrass canopy cover was estimated using a 50 cm × 20 cm Daubenmire quadrat positioned at the same locations as the 1 m × 1 m density quadrats. Canopy cover was visually estimated for each species using six predefined cover classes (Table 1). The midpoint of each class was used as the representative percentage value for calculating mean canopy cover.

Table 1: Cover classes and midpoint values used for estimating seagrass canopy cover

Cover Class	Range of Coverage (%)	Midpoint (%)
1	0-5 %	2.5 %
2	5-25 %	15.0 %
3	25-50 %	37.5 %
4	50-75 %	62.5 %
5	75-95%	85.0 %
6	95-100	97.5 %

For each species, the number of quadrats within each cover class was multiplied by the corresponding midpoint value. The products were summed and divided by the total number of quadrats containing that species:

$$\text{Mean canopy cover (\%)} = \frac{\sum(ni \times mi)}{\text{N}}$$

where ***ni*** is the number of quadrats in cover class ***i***, ***mi*** is the midpoint percentage of that class, and ***N*** is the total number of quadrats assessed for the species. Only seagrass canopy was considered; non-seagrass vegetation was excluded.

Results

Spatial distribution of seagrass: The 2025 remote-sensing assessment mapped 787.80 ha (7.88 km²) of seagrass within the surveyed MNP&S. Distribution was highly uneven among locations. The Bhaider–Noru–Chank–Mitha-Khara Chusna–Tam Reef complex accounted for 503.22 ha (63.9%) of the total mapped area. Narara and Kalubhar contributed a further 73.82 and 59.76 ha, respectively. Collectively, these three locations accounted for 636.80 ha (80.8%) of the mapped seagrass area. The remaining 17 locations together contributed only 19.2% (Table 2 & Image 2).

The distribution was strongly right-skewed, with a few large meadow complexes accounting for most of the mapped area and numerous islands supporting relatively small patches. The mean mapped area per location was 39.39 ± 111.85 ha, with a median of only 4.01 ha, indicating substantial spatial heterogeneity. Excluding the large Bhaider–Noru–Chank–Mitha-Khara Chusna–Tam Reef complex, the mean area decreased to approximately 14.97 ha, demonstrating that the overall mean was strongly influenced by this single extensive meadow complex.

The present mapped extent of 7.88 sq. km is lower than the 24.32 sq.km reported for the MNP&S by (Kamboj R.D. 2014), representing a difference of approximately 67.6% in reported mapped extent. However, this difference should not be interpreted as a confirmed temporal decline because the two assessments differed in imagery, spatial resolution, classification methodology, survey period and potentially spatial coverage. Similarly, the approximately 17 sq.km. estimate reported for the Gulf of Kachchh by (Geevarghese et al. 2018) represents a broader geographical unit than the present MNP&S assessment. Therefore, these estimates provide contextual comparisons rather than direct temporal trend estimates. A standardized multi-temporal analysis using comparable imagery, classification procedures and field-validation datasets would be required to quantify actual changes in seagrass extent.

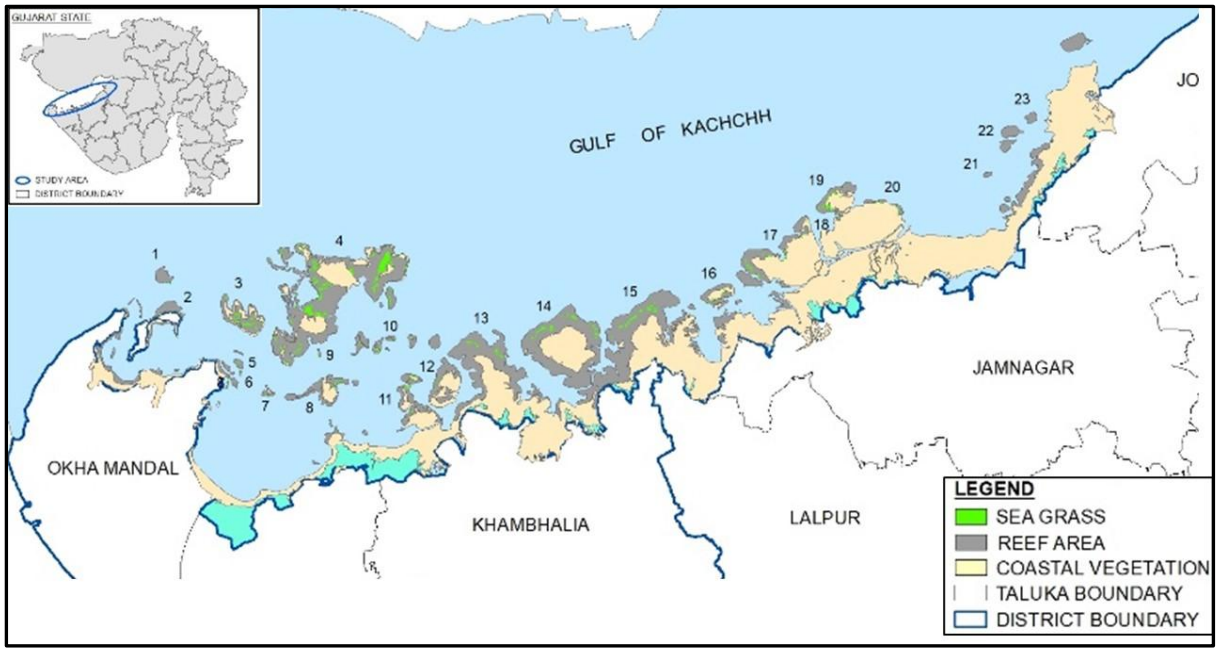

Image 2: Spatial distribution of seagrass across MNP&S locations

Table 2. Spatial distribution of seagrass in the MNP&S

Sr. No.	Location Code (Image-2)	Seagrass location	Area (ha)	Area (%)
1	4	Bhaider, Noru, Chank, Mitha-Khara Chusna, Tam Reef	503.22	63.88
2	15	Narara Island	73.82	9.37
3	14	Kalubhar Island	59.76	7.59
4	3	Paga Reef	38.2	4.85
5	13	Dhani Island	28.66	3.64
6	19	Pirotan Island	21.62	2.74
7	17	Dedeka Mundeka Island	18.76	2.38
8	11	Panero Island	13.83	1.76
9	10	Vuda Kuda Reef	7.39	0.94
10	20	Chhad-jindra Island	4.76	0.6
11	16	Goose Island	4.42	0.56
12	8	Ajad Tapu	4.01	0.51
13	12	Gandhiya Kado	3.55	0.45
14	5	Boriya Reef	1.98	0.25
15	7	Pashu Island	1.23	0.16
16	9	Bural Pinnacle	1.03	0.13
17	1	Chindri Island	0.85	0.11
18	6	Poshitra Islands	0.48	0.06
19	2	Beyt Island	0.22	0.03
20	18	Bhains Bet	0	0
Total			787.8	100

Species composition and distribution: Three species were recorded from the five islands quantitatively sampled: *Halophila ovalis*, *Halodule uninervis* and *Halophila beccarii*. *H. ovalis* occurred at all five islands, *H. uninervis* at four, and *H. beccarii* at three. Thus, the occurrence breadth was 100%, 80% and 60%, respectively. The species assemblage therefore showed a clear dominance of *H. ovalis* in terms of spatial occurrence. However, species

dominance varied among islands. *H. ovalis* was the principal species at Narara, Dhani and Kalubhar, whereas *H. beccarii* had the greatest relative composition at Dedeka-Mundeka and *H. uninervis* was prominent at Pirotan. This indicates that species dominance was spatially heterogeneous rather than uniform across the sampled meadows.

Leaf-pair density and species dominance: Across the five islands, *H. ovalis* had the highest mean density (352.06 ± 178.99 leaf pairs m^{-2}), followed by *H. beccarii* (128.13 ± 157.72 leaf pairs m^{-2}) and *H. uninervis* (79.74 ± 89.68 leaf pairs m^{-2}). The coefficient of variation (CV) was 50.8% for *H. ovalis*, compared with 123.1% for *H. beccarii* and 112.5% for *H. uninervis*. Thus, *H. ovalis* showed comparatively consistent density among islands, whereas the other two species exhibited much greater spatial variability. The highest individual density was recorded for *H. ovalis* at Narara (499.33 leaf pairs m^{-2}), while the lowest was for *H. uninervis* at Dhani (9.38 leaf pairs m^{-2}). *H. beccarii* showed its maximum density at Dedeka-Mundeka (320.21 leaf pairs m^{-2}), indicating a strong site-specific concentration (Table 3).

The relative composition data demonstrated pronounced differences in species dominance among islands. At Kalubhar, *H. ovalis* represented 100% of the recorded leaf pairs. At Narara and Dhani, it contributed 88.20% and 62.26%, respectively. In contrast, *H. beccarii* accounted for 60.09% of the recorded leaf pairs at Dedeka-Mundeka, while *H. uninervis* contributed 47.05% at Pirotan. Thus, the quantitative data identify three distinct patterns i) *H. ovalis*-dominated: Kalubhar, Narara and Dhani, ii) *H. beccarii*-dominated: Dedeka-Mundeka and iii) Mixed *H. ovalis–H. uninervis* meadow: Pirotan (Table 3).

Canopy cover: Mean canopy cover across the five islands was highest for *H. ovalis* (12.69 ± 7.96%), followed by *H. beccarii* (3.31 ± 4.42%) and *H. uninervis* (2.17 ± 2.92%). The CV was highest for *H. uninervis* (134.4%) and *H. beccarii* (133.3%) and lower for *H. ovalis* (62.7%), again indicating greater spatial variability in the distribution of the former two species. *H. ovalis* showed its maximum canopy cover at Dhani (21.85%), whereas *H. beccarii* attained its highest cover at Dedeka-Mundeka (10.04%) and *H. uninervis* at Pirotan (6.92%) Table 3.

Relationship between density and canopy cover: An additional analysis of the island-level data showed a strong positive association between leaf-pair density and canopy cover when the three species and available island observations were considered together (Pearson's $r \approx 0.81$, $n = 13$). This indicates that locations with higher leaf-pair density generally exhibited higher canopy cover (Fig 1).

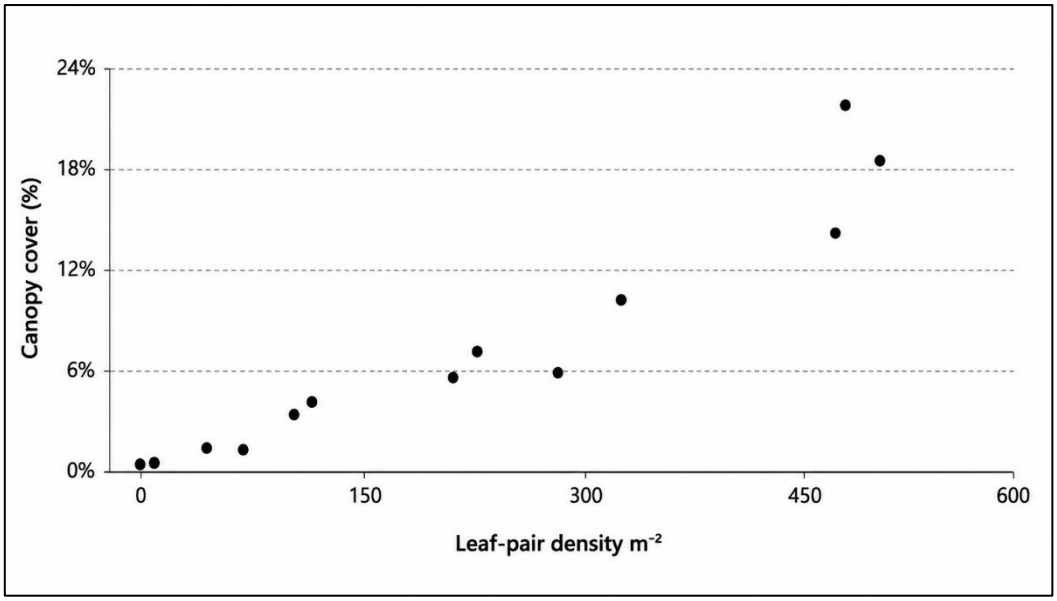

Fig 1. Relationship between Density and Canopy Cover

Discussion

Spatial concentration of seagrass: The most notable spatial feature of the present study was the strong concentration of mapped seagrass within a limited number of reef complexes. More than four-fifths (80.8%) of the mapped area occurred within the Bhaider–Noru–Chank–Mitha-Khara Chusna–Tam Reef complex, Narara and Kalubhar. This spatial concentration suggests that seagrass distribution within the MNP&S is not uniform and that conservation and monitoring efforts should account for the unequal contribution of individual reef systems.

Previous studies have also documented considerable spatial variation in seagrass occurrence within the Gulf of Kachchh (Adhavan et al. 2022; Geevarghese et al. 2018; Kamboj R.D. 2014). Environmental variables such as sediment characteristics, turbidity, water movement and depth can influence seagrass distribution, although these factors were not simultaneously measured in the present spatial analysis and therefore cannot be identified as causal drivers here.

The difference between the present estimate and previous estimates is important for monitoring but should not be described as confirmed seagrass loss. Kamboj R. D. (2014) reported 24.32 km² for the MNP&S, while Geevarghese et al. (2017) estimated approximately 17 km² for the Gulf of Kachchh. Differences among estimates may arise from methodological and spatial differences. Geevarghese et al. (2017), for example, used satellite-based geospatial assessment, whereas the present study used 2025 LISS-IV imagery and a different classification workflow. Consequently, the present value should primarily be regarded as a contemporary spatial baseline.

Dominance of *Halophila ovalis*: The quantitative data consistently identified *H. ovalis* as the most widespread and numerically dominant species. Its occurrence at all five sampled islands, highest mean density and comparatively lower coefficient of variation indicate a broader and more consistent distribution than the other two species.

The predominance of *H. ovalis* is consistent with previous observations from the Gulf of Kachchh. (Adhavan et al. 2022) also reported *H. ovalis* as an important component of seagrass meadows at Pirotan, Narara and Mithapur. However, the much higher densities recorded in some present sites should not be interpreted as a temporal increase because the sampling designs and analytical approaches were not identical.

Site-specific importance of *Halophila beccarii*: Although *H. beccarii* occurred at only three of the five sampled islands, its high density and relative composition at Dedeka-Mundeka are important. The species contributed 60.09% of the recorded leaf pairs at this island and had a density of 320.21 leaf pairs m^{-2}. The high CV of *H. beccarii* (123.1%) indicates that its abundance was strongly spatially variable. This contrasts with *H. ovalis*, which showed a substantially lower CV (50.8%). Thus, the present results suggest that *H. beccarii* is locally abundant but spatially restricted, rather than uniformly distributed across the sampled islands. This finding is conservation-relevant because *H. beccarii* is globally categorized as Vulnerable. However, the present data alone do not establish population decline or extinction risk at the local scale. Dedeka-Mundeka should instead be considered a priority site for species-specific monitoring based on its observed abundance and frequency.

Spatial differentiation in meadow structure: The species-composition results reveal considerable differentiation among islands. Kalubhar supported a monospecific *H. ovalis* assemblage in the sampled quadrats, whereas Dedeka-Mundeka was dominated by *H. beccarii* and Pirotan had a relatively mixed contribution of *H. ovalis* and *H. uninervis*.

Density–canopy relationship: The positive relationship between leaf-pair density and canopy cover provides an additional ecological signal from the dataset. The correlation of approximately **r = 0.81** suggests that greater numerical abundance was generally associated with greater canopy development. This is ecologically plausible because increasing numbers of leaves can increase the proportion of the substrate occupied by above-ground plant material. Nevertheless, the relationship should not be interpreted as a causal model. Canopy cover is also influenced by leaf size, orientation, shoot architecture and meadow structure. Moreover, the present analysis uses aggregated observations.

Table 3: Quantitative ecological attributes of seagrass species across the sampled islands of MNP&S

Island	Scientific Name	Density (leaf pairs m^{-2})	Abundance	Frequency (%)	Relative composition (%)	Canopy Cover (%)
Dedeka-Mundeka	*Halodule uninervis* (Forssk.) Boiss.	100.36	468.33	21.43	18.83	3.00
	Halophila beccarii Asch.	320.21	448.30	71.43	60.09	10.04
	Halophila ovalis (R.Br.) Hook.f.	112.36	524.33	21.43	21.08	3.75
Dhani	*Halodule uninervis* (Forssk.) Boiss.	9.38	225.00	4.17	1.23	0.10
	Halophila beccarii Asch.	277.92	1667.50	16.67	36.51	5.58
	Halophila ovalis (R.Br.) Hook.f.	474.00	494.61	95.83	62.26	21.85
Kalubhar	*Halophila ovalis* (R.Br.) Hook.f.	467.13	467.13	100.00	100.00	14.09
Narara	*Halodule uninervis* (Forssk.) Boiss.	66.83	267.33	25.00	11.80	0.83

Island	Scientific Name	Density (leaf pairs m^{-2})	Abundance	Frequency (%)	Relative composition (%)	Canopy Cover (%)
	Halophila ovalis (R.Br.) Hook.f.	499.33	499.33	100.00	88.20	18.46
Piroton	*Halodule uninervis* (Forssk.) Boiss.	222.11	363.45	61.11	47.05	6.92
	Halophila beccarii Asch.	42.50	382.50	11.11	9.00	0.94
	Halophila ovalis (R.Br.) Hook.f.	207.50	266.79	77.78	43.95	5.31

Conclusion: The study recorded 7.88 km² (787.80 ha) of seagrass in the MNP&S, with its distribution concentrated in a few major reef and island complexes. Three species viz., *Halophila ovalis*, *Halodule uninervis* and *Halophila beccarii* were recorded, with *H. ovalis* being the most widespread and dominant, while *H. beccarii* showed localized dominance at Dedeka-Mundeka. Differences from earlier estimates emphasize the need for standardized long-term remote-sensing and field monitoring before inferring temporal changes. The present findings provide a baseline for spatial distribution and community structure and support site-specific conservation and monitoring of seagrass meadows in the MNP&S.

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