



Loss of Dugong grass [*Halophila ovalis* (R. Brown)] population structure due to habitat disturbance in an island ecosystem

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Received 24 March 2020; revised 12 October 2020

Seagrass ecosystems are lost due to habitat disturbance, coastal development, and human activities. The impact of boat anchors from traditional fishing and recreational activities was assessed on the seagrass *Halophila ovalis* from the Andaman and Nicobar Islands (ANI) of India. The plant density, biomass, morphometrics, canopy height and percentage cover were estimated from two sites of Govind Nagar beach of ANI. The shoot density of *H. ovalis* was reduced by physical damage caused by boat anchors. The morphometrics of *H. ovalis*, such as the number of leaves per ramet, leaf length, width, and horizontal rhizome length was significantly reduced when impacted by boat anchors. Seagrass canopy height and percentage cover were reduced by 71 and 54 %, respectively. Though the impact of boat anchors reported here is on a small-scale, it may impact the feeding grounds of locally endangered dugongs. Therefore, proper management and preventive measures should be implemented to prevent the loss of dugong grass habitats from tourism, recreational, and fishing activities.

[**Keywords:** Anthropogenic disturbance, Boat anchoring, Habitat loss, Meadow traits, Seagrass tropical islands, *Halophila ovalis*, India]

Introduction

Seagrass ecosystems represent one of the richest and widely distributed coastal habitats in the ocean, that provide 24 different types of ecosystem services and support a range of keystone and ecologically important marine species from all trophic levels^{1,2}. Seagrass ecosystems form important habitats and nurseries to 1/5th of 25 commercially important fish populations and provide feeding grounds for endangered sea cows and seahorses³. This provisioning of seagrass supports the livelihood of millions of coastal communities^{2,3}. Though seagrass ecosystems provide valuable ecosystem services and play a significant role in maintaining coastal trophic structure, they are declining globally (~ 35 % lost) under the influence of anthropogenic pressure⁴. Recent reports have indicated that 11 species of seagrass worldwide are under extinction risk, whereas three species are endangered¹.

One of the major contributors to seagrass decline worldwide is coastal development and modification caused by human settlement, which reduces coastal water quality through nutrient enrichment leading to eutrophication^{5,6}, increased sedimentation from land run-off, and increased tourism and fishing activities¹. Tourism and fishing activities utilize various boats,

which deploy boat anchors. Boat anchors are of serious concern⁷ as they cause long-term small-scale physical disturbance and permanent damage to shallow water seagrass roots and rhizome structures resulting in loss of seagrass meadows⁸. The loss of seagrass meadows due to boat anchors has been documented in India for various seagrass species of Palk Bay and Gulf of Mannar region⁹. Outside India, it has been reported for species like *Zostera marina* (Linnaeus) from San Francisco Bay, USA¹⁰ and Studland Bay, UK^{11,12}, *Posidonia oceanica* [(Linnaeus) Delile] in the Mediterranean Sea^{13,14} and for mixed seagrass species of Rottneest Island, Australia¹⁵. Loss of seagrass meadows eventually resulted in the loss of valuable ecosystem services, such as the release of stored carbon of 4.2 kg C_{org} m⁻²(ref.15) and loss of fish habitats and feeding grounds for seacows¹².

India has an estimated cover of 517 km² of seagrass beds consisting of 7 genera and 16 species distributed along its coastline including Andaman and Nicobar Islands (ANI)^{16,17}. The seagrass *Halophila ovalis* (R. Brown) has a pan India distribution and it occurs around the east coast at the Chilika lagoon of Odisha¹⁸, Gulf of Mannar of Tamilnadu¹⁷, and ANI¹⁹. 13 out of 16 seagrass species are found at ANI, covering an area

of 29.42 km² and are distributed around mudflats and sandy regions from the intertidal zone to 10-15 m depth¹⁹. *Halophila ovalis* has a frequent occurrence around ANI mostly in the intertidal regions, as individual patches or mixed with other seagrass species such as *Halodule uninervis* [(Forsskål) Asch.] and *Thalassia hemprichii* [(Ehrenberg) Asch.]^{20,21}. *Halophila ovalis* is the fastest-growing seagrass species in this region¹⁹ and is a preferred food source for the endangered *Dugong dugon*²². Swaraj Dweep (hereafter referred to as Havelock Island) is home to the endangered *Dugong dugon*, which depends on the *H. ovalis* beds for its feeding²³.

Tourism is a major source of income in Havelock Island of ANI because of its natural beaches and underwater marine life, such as coral reefs and associated biodiversity. Being a tourist hotspot, these islands have had a rapid increase in the number of boats operating at this island for SCUBA diving, fishing (traditional and recreational), and various other recreational activities. However, the impacts of increased boat anchoring on seagrass species of ANI are not well documented. Therefore, this study evaluated the density, biomass, morphometrics, and

canopy structure of *H. ovalis* meadows of Havelock Island under the influence of boat anchoring to understand the impact on seagrass population structure.

Materials and Methods

Study site

Havelock Island is located in the southeast region of the Andaman and Nicobar Islands of India (Fig. 1). The island has tidal amplitude of 2.45 m, 26.28 to 31.67 °C temperature range, and salinity range between 32 to 35 psu. Two sites within Govind Nagar beach and Havelock Island were selected for this study (Fig. 1). The number of fishing and recreational boats anchored here is about ~ 120 at site 1 and ~ 15 at site 2. This site 1 had only anchors deployed and there was no sign of moorings deployment. The sites were 500 m apart and were separated by dead coral patches. Site 1 has a high number of anchored boats and the anchor trails and holes were visible (Fig. 2c); whereas site 2 was sheltered by a mixed patch of live and dead corals. The patches of study sites where a considerable amount of seagrass biomass was available for the collection were selected during the present study.

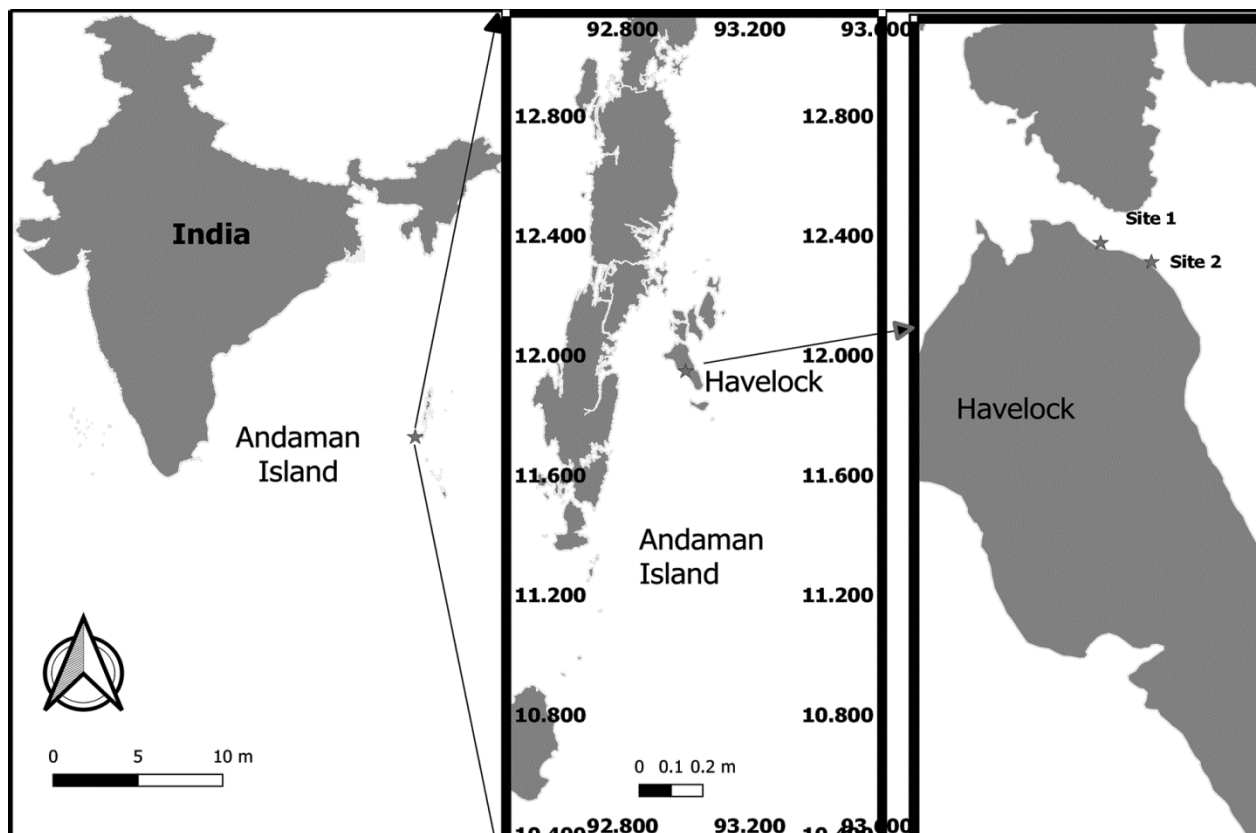


Fig. 1 — Study area showing site 1 and 2 of Havelock island of ANI, India



Fig. 2 — *H. ovalis* patches at highly anchored site 1 (a), sheltered site 2 (b), and type of anchors used (c)

Sediment sampling and analysis

Sediment cores ($n = 12$) were collected from each quadrat where seagrass was sampled using a 5 cm diameter and 10 cm long plastic core. Sediments were collected in plastic bags and brought to the laboratory. In the laboratory, sediment samples were oven-dried at 60 °C for 72 hours before being sieved for grain size fractions (500, 150, 75, and 63 μm).

Seagrass sampling and analysis

A quadrat of 20 cm x 20 cm and a hand shovel was used to dig out seagrass samples up to 10 cm depth in February-March 2019. Twelve quadrats of *H. ovalis* were collected during low tide within a depth of 0.5 m from a transect of 10 m x 1.5 m perpendicular to the beach from each site. Sampling was carried out randomly within the transect covering the whole transect area at both sites. The *H. ovalis* beds were monospecific at both sites (Figs. 2a & b). From each quadrat, seagrass leaves, rhizomes, and roots were collected in plastic bags and brought to the laboratory for further analysis. In the laboratory, the plant samples were washed again with double distilled water and the leaf epiphytes were scraped off by a plastic razor. Density (no. m^{-2}) was calculated by counting the total number of shoots per quadrat. Horizontal rhizome length ($n = 15/\text{quadrat}$) were measured for the rhizomes with apex shoot attached. Leaf length (cm), width (mm) and height (cm) from shoot ($n = 20/\text{quadrat}$) was measured using a Vernier Calliper (accuracy: 0.02 mm). The canopy height (cm) of *H. ovalis*, *i.e.*, the leaf length of the longest leaf from the sediment to the leaf tip was measured using a ruler²⁴. After initial measurements, the plant parts were separated and oven-dried at 60 °C for 48 hours to get the dry weight biomass (g DW m^{-2}). The above-ground (leaf biomass) and below-ground (rhizome + root) biomass were used to estimate the biomass ratios. The percentage cover of the seagrass was estimated (visually) from the area covered by

Table 1 — Results of grain size analysis of sediments and various *H. ovalis* traits from the anchor impacted (site 1) and sheltered (site 2) area of Havelock Island of ANI, India. Mean \pm Standard error (SE) values are presented. Small letters indicate significant differences between the two sites. One-way ANOVA p -values are presented. Above ground (AB), Below ground (BG), and No values (nv)

Variables		Site 1	Site 2	p -value
Grain size (%)	Sand	94.05 \pm 5.55 ^a	85.25 \pm 4.15 ^a	< 0.001
	Silt	5.95 \pm 2.39 ^a	14.75 \pm 2.09 ^b	< 0.001
Biomass (g DW m^{-2})	AB	0.71 \pm 0.24 ^a	1.68 \pm 0.23 ^b	0.019
	BG	2.72 \pm 0.14 ^a	4.14 \pm 0.79 ^b	< 0.001
	AB:BG	0.32 \pm 0.04	0.57 \pm 0.22	nv
No. of leaves shoot ¹		5.87 \pm 0.45 ^a	10.22 \pm 0.87 ^a	0.675
Canopy height (cm)		1.15 \pm 0.04 ^a	4.20 \pm 0.01 ^b	< 0.001
Leaf length (cm)		1.02 \pm 0.09 ^a	2.05 \pm 0.09 ^b	0.004
Leaf width (cm)		0.94 \pm 0.01 ^a	1.23 \pm 0.08 ^b	< 0.001
Horizontal rhizome length (cm)		9.05 \pm 0.08 ^a	15.26 \pm 0.38 ^b	0.008
Percentage cover (%)		20.30 \pm 0.12	44.50 \pm 0.89	nv

seagrass to the total quadrat (nine small quadrats) area.

Statistics

One-way ANOVA was used to test the significant differences between *H. ovalis* density, biomass, and morphometric features between the two sites. All data were pre-checked for normality and homogeneity of variance. Data were log-transformed when normality and homogeneity of variance were not achieved for raw data. Data is presented as mean and standard error (S.E.). SIGMAPLOT ver. 11 was used for the statistical analysis.

Results and Discussion

The negative impact of habitat disturbance by boat anchors on *H. ovalis* was evident compared to that of sheltered areas. Sand constituted 85 to 94 % of the sediment grain size fractions (coarse, fine, and very fine), whereas silt content was low. The silt content at site 1 was 2.47-fold lower than site 2 (Table 1) which may reflect the continued disturbance of the upper layer of the sediment by boat anchors resulting in

mobilization and dispersion of the impacted sediments by daily wave action and crab holes¹² leading to loss of the fine fraction of sediment at site 1. Sediment grain size (fine fractions) helps the seagrass retain nutrients and essential trace elements for primary production⁷. However, change in resident sediment fractions can alter the seagrass population structure and thus have negative impacts on seagrass growth as *H. ovalis* needs higher silt content for better growth and production²². Lower silt and higher sand content can result in the loss of shoot density as this proportion of sediment increases the penetration of anchors and cause subsequent damage to the seagrass rhizome structure¹³. The combination of sediment erosion by boat anchors and wave dynamics may lead to release of buried sediment organic carbon stocks and can convert affected seagrass meadows to a source of carbon rather than carbon sinks as reported for seagrass meadows of Rottneest Island, Australia which was affected by boat anchoring and mooring¹⁵.

The shoot density of *H. ovalis* was significantly different between the two sites, whereas the apex density was similar (Fig. 3). The total density (shoot + apex) observed at site 1 (391.7 ± 11.7 shoots m^{-2}) was lower and site 2 (454.7 ± 47.0 shoots m^{-2}) density was similar (427.2 ± 24.8) to the reported values of *H. ovalis* from the coast of Palk Bay, India²⁵. However, the density values were higher than the density of *H. ovalis* from the east coast of Malaysia²⁶. Lower shoot density at site 1, indicates physical damage caused by boat anchors to the shoot structures of *H. ovalis*, similar to boat anchors impact on *P. oceanica* of the Turkish coast in the Mediterranean Sea⁷. However, the damage to the shoot structure of *H. ovalis* is highly

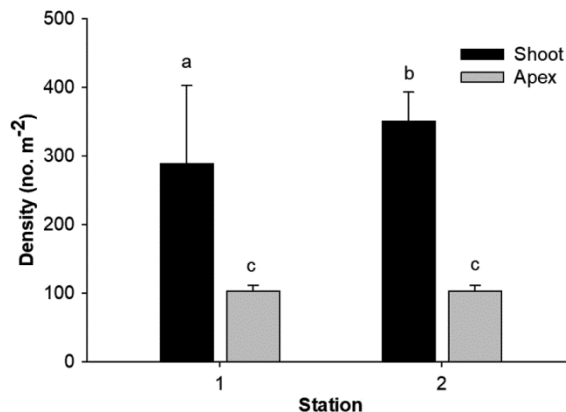


Fig. 3 — Shoot and apex density (no. m^{-2}) of *H. ovalis* at site 1 and site 2 of Havelock Island, ANI. Small letters indicate significant difference between sites derived from one-way ANOVA analysis

significant as plant structure is very fragile and easily breakable compared to the rigid shoot structure of *P. oceanica*. Secondly, *H. ovalis* is generally found in the upper intertidal regions which are subjected to high wave action that can damage its physical integrity²⁰.

The above-ground (AG) and below-ground (BG) biomass of *H. ovalis* were significantly different between the two sites. The AG and BG biomass of site 1 were 2.3-fold and 1.5-fold lower respectively, whereas the AG: BG ratio of biomass was 1.7-fold lower than site 2 (Table 1). Lower AG biomass in other seagrass species such as *Halophila beccarii* (Aschers.) has also been observed around the Andaman Sea under the influence of similar intertidal conditions²⁷. The BG biomass of site 1 (71 %) and site 2 (79 %) coincide within the range of BG biomass of 63-77 % observed for *H. ovalis* meadows around the Andaman Sea²⁶. Though the BG biomass at site 1 was lower than site 2, its contribution in the plant total biomass was higher than site 2 (Table 1). This suggests that *H. ovalis* having a smaller plant structure (roots and rhizomes), needs extensive rhizome networks buried in the sediment to withstand the sand wave breaking at this site. Secondly to survive the anchoring damage it needs to migrate spatially to more favorable conditions. Consequently, in response to habitat disturbance, *H. ovalis* increases its BG biomass and bed patchiness, which has been observed in *H. ovalis* and other seagrasses like *T. hemprichii* and *Halodule uninervis* [(Forsskål) Asch.] of the coast of Indonesia subjected to cyclone disturbance and intense grazing²⁸. This extensive rhizome network also helps withstand anchoring damage and facilitates spatial migration of the plant to a suitable habitat, which has been observed for *T. hemprichii* from the Havelock Island of ANI²⁰.

The morphometrics of *H. ovalis* was significantly different between the two sites, (Table 1). Between the two sites, the number of leaves per ramet was higher (10.22 ± 0.88) at site 2. Both the leaf length (1.02 ± 0.09 cm) and width (0.94 ± 0.01 cm) of *H. ovalis* at site 1 were 2-fold and 1.3-fold lower than site 2. The number of leaves per ramet, length, and width of *H. ovalis* at site 1 were lower than site 2 (Table 1) as a result of the bending of the leaf stem by the rope and anchors and subsequent breakage and burial of leaf structure in the upper layer of the sediment (Fig. 2a). This leaf breakage inhibits plant growth, productivity, and AG biomass. Physical damage by boat anchors and reduction in leaf length and width has been observed for *T. hemprichii* from Havelock Island of ANI²⁰ and

for seagrass species like *P. oceanica* in the Mediterranean Sea¹⁴.

The canopy height of seagrass at site 1 was 3.6-fold lower than site 2 (Table 1), indicating the physical injury/breakage of the leaf structure during the drop-down of boat anchors leading to the formation of leaf scars and broken-down leaf-stems at the site 1. While anchored, the continuous swinging of the attached rope with the semi-diurnal tidal movement, the size of the anchor, and the settlement of the boat during the low tide on the seagrass canopy also play an important role in determining the extent of the damage. Once broken from the stem seagrass leaves are covered with sediments and microbenthic algae, which alternatively reduces the seagrass photosynthetic capacity and its resilience to meadow development. Anchor deployment and reduction of canopy height were also observed for *Zostera marina* in the UK¹², *P. oceanica* of Turkish coast in the Mediterranean Sea⁷ and *Posidonia australis* (J. D. Hooker) from the coast of Australia²⁹. The horizontal rhizome length was 1.6-fold shorter at site 1 than site 2 (Table 1), clearly indicating the negative impact of physical damage on the rhizome structure of *H. ovalis*. This damage results in meadow fragmentation and reduced spatial migration, even though *H. ovalis* has a higher growth rate. Loss of rhizome structure and negative effects on meadow migration has been observed for *T. hemprichii* around the Havelock Island of ANI²⁰ and *P. oceanica* in the Mediterranean Sea³⁰.

Reduction in morphometrics and density resulted in low percentage cover (20.3 ± 0.12 %) of *H. ovalis* at site 1, which was 2-fold lower than site 2 (Table 1). The observed canopy height of *H. ovalis* at site 1 was similar to the canopy height of *H. beccarii* (0.7-1.5 cm) observed at the Kalegauk Island, Myanmar²⁷ and *H. ovalis* (1.98 cm) on the east coast of Malaysia²⁶ in the Andaman Sea, where disturbances due to boat anchors have been reported. The negative impact of boat anchors on the morphometrics, resulting in low percentage cover has also been observed for other seagrass species like *Z. marina* in the UK¹² and USA¹⁰, *P. oceanica* in the Mediterranean Sea^{7,13,14} and *P. australis* in Australia¹⁵.

The loss of seagrass patches under the influence of boat anchors at the Havelock Island of ANI, India is small (within an area of 1 km²) but significant at the local scale (loss of suitable habitat) as these disturbances lead to the removal of *H. ovalis* biomass (AG and BG) by shoot uprooting and breakage of

leaves. These losses will directly impact the local biota that depends on *H. ovalis* meadows for food and habitat, such as *Dugong dugon* (which have been reported to visit this site for feeding), an endangered mammal found in the waters of ANI²³. Loss of their preferred feeding grounds can impact its conservation and recovery aspects. Saying that physical damages due to boat anchors may also result in fragmentation of the seagrass meadows and combined with other physical disturbance like sand wave breaking and trampling and tourism footfall can result in loss of plant physical structures^{5,6}. Loss of seagrass meadows will also reduce the extensive ecosystem services seagrasses provide, such as habitat for commercially important fish population and invertebrate biodiversity and carbon sequestration^{3,8,15}.

We report for the first time about the effects of boat anchors and increased tourism on seagrass ecosystems of ANI of India and found clear evidence that a combination of physical stressors combined with sand wave breaking and touristic footfall can cause loss of fragile *H. ovalis* patches. The loss of *H. ovalis* was mostly restricted to the area that had an increased anchor deployment compared to the sheltered site with a clear indication in the reduction of density, biomass, morphometrics, canopy height, and percentage cover. This damage to seagrass meadows is local on a scale within the beach, which can lead to loss of feeding habitat fish and dugong population. Therefore, an extensive survey is required around the island to get a more detailed picture of the loss of seagrass meadows due to tourism and fishing. This study suggests that proper management and planning should be placed for the conservation of coastal shallow-water seagrass ecosystems of ANI, which can be lost due to damage caused by boat anchors, direct fall of boats on seagrass meadows during low tides, and damage by recreational and tourism activities.

Conclusion

This study reported here for the first time about the impacts of boat anchors from tourism, recreational, and fishing activities on the population structure of shallow water Dugong grass (*Halophila ovalis*) for the Andaman and Nicobar Island ecosystem of India. The negative impacts of boat anchors deployment were observed on the *H. ovalis* density, above-ground biomass, leaf morphometrics, canopy height, and percentage cover. Loss of *H. ovalis* population structure can result in loss of feeding grounds for endangered mammals like *Dugong dugon* that inhabit

these islands. Our results will serve as a baseline for further research on the loss of shallow water seagrass ecosystems due to the impacts of tourism and fishing.

Acknowledgments

We are grateful to the PCCF, wildlife to provide the required official help during the sampling program. This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors. We are thankful to the reviewers for their suggestions to improve the manuscript.

Conflict of Interest

The authors declare there is no conflict of interest between any organizations or with funding agencies.

Authors Contribution

AKM: Conceptualization, methodology, formal analysis, investigation, writing and visualization. S N: Conceptualization, resources, writing-review and editing. DA: Conceptualization, resources, writing-review, editing and supervision.

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