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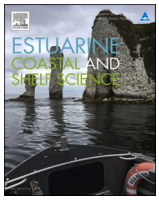

Seascape connectivity has low influence on seagrass blue carbon in tropical oligotrophic Islands

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ABSTRACT

Seagrass meadows are important blue carbon sinks, yet significant knowledge gaps exist in understanding the role of seascape connectivity in influencing carbon (C) and nitrogen (N) stocks. This study addressed this existing knowledge gap, by quantifying the sediment and seagrass (*Thalassia hemprichii*) biomass C and N stocks, and utilized stable isotope non-connected modelling to assess the contribution of various sources to the sediment C pool in non-connected (with other seagrass) and connected (with mangroves) meadows in the Andaman and Nicobar Islands, India. We observed that non-connected meadows sediment contained 3.7-fold higher total N, and enriched $\delta^{13}C$ and $\delta^{15}N$ values compared to connected meadows. Contrastingly, the sediment in connected meadows exhibited higher organic matter, total C, and more depleted $\delta^{13}C$ and $\delta^{15}N$. Surficial sediment C stocks (3.50 ± 1.78 Mg C ha^{-1}) were higher in connected meadows, while N stocks (1.21 ± 0.71 Mg N ha^{-1}) were higher in non-connected meadows. Higher N availability could be led to higher density and biomass N stocks in non-connected meadows. Stable isotope mixing modelling indicated that the average contribution of *T. hemprichii* biomass was highest (0.69 ± 0.13 %) to the sediment C pool, followed by other seagrass biomass in non-connected meadows. In connected meadows, the mean contribution of *T. hemprichii* biomass (0.68 ± 0.10 %) was also higher than mangrove C sources. This study highlights that the influence of seascape connectivity for cross habitat subsidies of C and organic matter is lower than connected seagrass meadows in intertidal oligotrophic island ecosystems of the Indian Ocean region.

1. Introduction

Seagrasses are important coastal macrophytes that inhabit intertidal zones to a depth of 150 m and create unique ecosystems. These unique ecosystems are distributed worldwide and provide an array of ecosystem services (McKenzie et al., 2020a; Mtwana Nordlund et al., 2016). Seagrasses combined with mangroves, and saltmarshes are collectively known as 'blue carbon ecosystems' and are considered as keystone coastal ecosystems for climate change mitigation (through carbon sequestration) and adaptation (Stankovic et al., 2023; Mishra et al., 2023; Saderne et al., 2019). The two important characteristics that make these blue carbon ecosystems as important carbon sinks are i) high primary productivity combined with low respiration rates resulting in carbon accumulation in biomass (Fu et al., 2023) followed by ii) enhanced carbon (C) sequestration in the sediment due to shoot-root reducing water flow and trapping finer sediment particles (Miyajima et al., 2015; Barcelona et al., 2021; Potouroglou et al., 2017). These characteristics results in increased accumulation of both autochthonous and allochthonous C sources in the sediment resulting in higher global carbon burial rates in seagrass (61–268 Tg C yr^{-1}), saltmarsh (31–34 Tg C yr^{-1}) and mangroves (48–112 Tg C yr^{-1}) compared to 49.3–78 Tg C yr^{-1} in terrestrial forests (Krause-Jensen and Duarte, 2016; Saavedra-hortua et al., 2019). Given that sediment C pool is influenced by both autochthonous and allochthonous derived sources, understanding the influence of seascape connectivity between these blue carbon ecosystems and their role as donors or recipients of C is essential (Mishra et al., 2025a). Seagrass ecosystems are also efficient in trapping organic matter (OM) and nutrients; especially nitrogen (N) and phosphorous (P) from coastal waters. This nutrient retention helps in reducing the negative effects of high N concentrations on surrounding coastal

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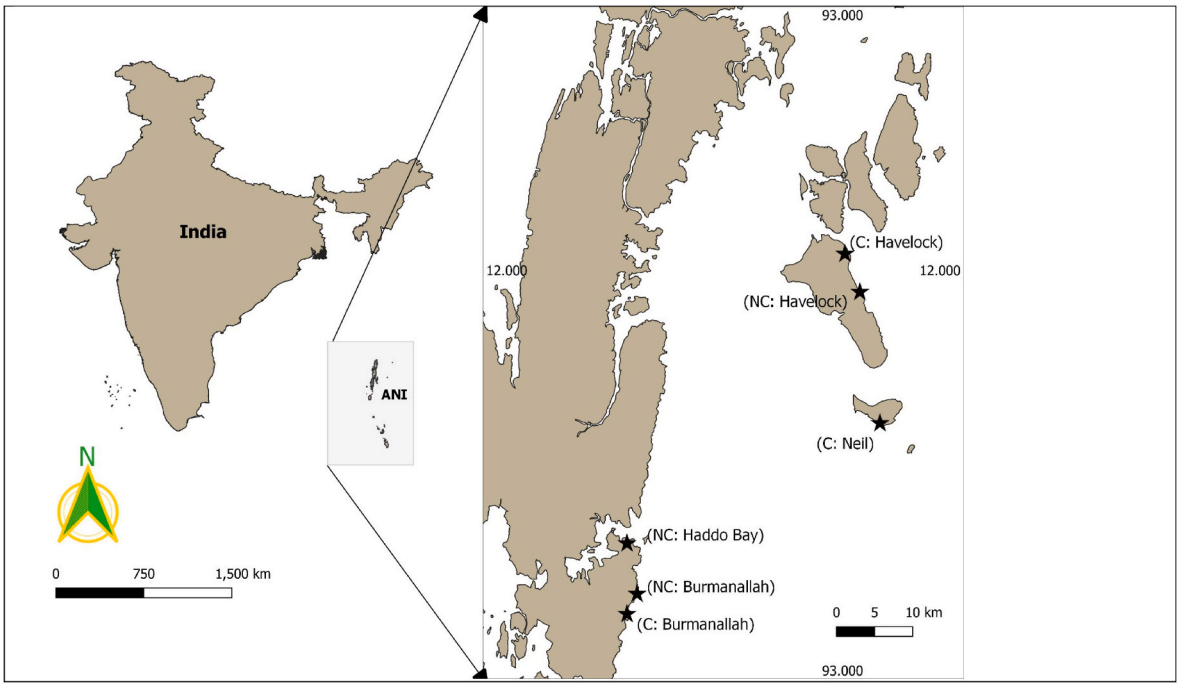

Fig. 1. Map of the study locations showcasing the locations of *T. hemprichii* present with non-connected seagrass (NC) and adjacent to mangroves (C) from the coast of ANI, India.

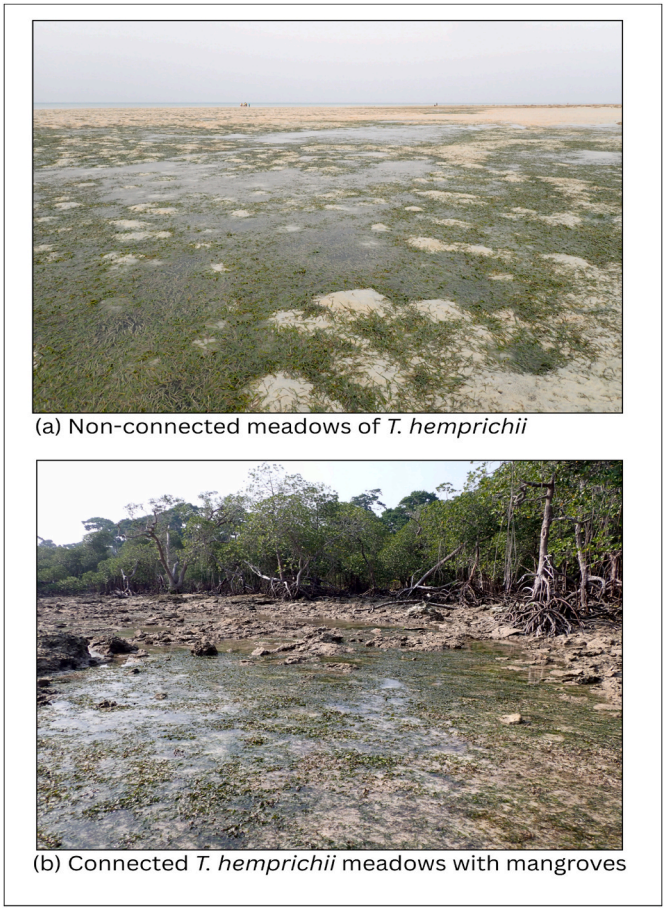

Fig. 2. Field pictures of a) non-connected *T. hemprichii* meadows and b) connected with mangroves from our study location of ANI, India. Picture credit; Amrit Kumar Mishra.

ecosystems (Wang et al., 2022; Mishra and Farooq, 2025; Mishra et al., 2025b; Román et al., 2019).

Seascape connectivity plays an important role in transfer of OM, nutrients and C across the connected seascape through tidal flows between seagrass-mangroves or seagrass-saltmarshes (Mishra et al., 2025b; Saintilan et al., 2013). This tidal inflow brings in high amount of nutrients, C and minerals from donor ecosystems (e.g., mangroves, saltmarshes) that accumulate in seagrass sediments and helps in enhancing seagrass growth and productivity, seagrass population demography, biodiversity assemblages and most importantly C sequestration (Guo et al., 2025; Asplund et al., 2021a; Mazarrasa et al., 2018a; Mishra et al., 2025c). Mangrove forests often out-well nutrients and OM to connected seagrass meadows, but some mangrove forests also experience in-welling of these matter and energy from seagrasses (Hyndes et al., 2014; Mishra and Kumar, 2020). However, ecosystem attributes such as the total area coverage by mangroves and riverine input into these mangroves plays an important role in modulating the capacity for out-welling and storage (Mishra et al., 2025c; Serrano et al., 2016; Popova et al., 2019). Furthermore, globally blue carbon studies that have explored the seascape connectivity approach is limited especially for seagrass ecosystems (Huxham et al., 2018). Most importantly this limitation is highlighted in the Indian Ocean bioregion, that hosts the most diverse group of seagrass species (n = 24) that are associated with other seagrasses or present adjacent to mangroves (Mishra et al., 2025b; McKenzie et al., 2020b). An increase of OM and C accumulation in seagrass ecosystems due to the transfer of materials and C from surrounding mangrove habitats have recently been documented for few oligotrophic islands of the Indian Ocean region such as Andaman and Nicobar Islands, India (Mishra et al., 2023; Mishra and Apte, 2020), Western Gulf of Thailand (Yeemin et al., 2024) or in the Western Indian Ocean (Gullström et al., 2018). These limited studies showcase that the presence of mangroves increases the transfer of OM and C to the adjacent seagrass ecosystems and hence their C storage. However, other processes at the seascape level such as exchange of particulate organic matter (POM) and accumulation of allochthonous OM in the sediment is still limited. Additionally, knowledge gap exists on the impact of various drivers (e.g., plant morphometrics, sediment traits and cross habitat

Table 1
Mean ± SD of sediment and *T. hemprichii* variables across non-connected and connected meadows from the coast of ANI, India. Statistical significance ($p < 0.05$) was derived from unpaired *t*-test between non-connected and connected meadows. Results of *t*-test are presented in Supplementary Table S2. Total Biomass (Above-ground + below-ground). Not significant (ns).

Sediment/Seagrass	Variable	Non-connected	Connected	*p-value*
Sediment	Sand (%)	66.18 ± 6.73	56.06 ± 22.55	<0.05
	Fine fraction (FF%)	33.82 ± 16.76	43.94 ± 12.55	<0.05
	OM (%)	3.64 ± 0.66	4.55 ± 1.73	<0.05
	DBD (g cm^{-3})	0.12 ± 0.05	0.16 ± 0.06	ns
	C (%)	2.03 ± 0.50	3.02 ± 0.94	<0.0001
	N (%)	0.90 ± 0.33	0.24 ± 0.05	<0.0001
	$\delta^{13}C$ (‰)	−6.71 ± 1.87	−10.84 ± 5.25	<0.001
	$\delta^{15}N$ (‰)	7.14 ± 0.90	2.35 ± 0.83	<0.0001
	C Stocks (Mg C ha^{-1})	2.61 ± 1.48	3.50 ± 1.78	<0.05
	N stocks (Mg C ha^{-1})	1.21 ± 0.72	0.29 ± 0.16	<0.0001
Seagrass (*T. hemprichii*)	Shoot Density (ind. m^{-2})	1104 ± 244.7	789.3 ± 251.12	<0.0001
	Apex Density (ind. m^{-2})	208.1 ± 86.03	148.6 ± 48.65	<0.001
	Total Biomass (g DW m^{-2})	424.6 ± 25.5	338.8 ± 63.4	ns
	Leaf C (%)	34.32 ± 1.33	34.19 ± 1.58	ns
	Leaf N (%)	1.85 ± 0.29	0.54 ± 0.13	<0.0001
	$\delta^{13}C$ (‰)	−7.88 ± 2.47	−7.53 ± 2.21	ns
	$\delta^{15}N$ (‰)	6.46 ± 0.65	2.24 ± 0.95	<0.0001
	Total Biomass C stocks (Mg C ha^{-1})	0.14 ± 0.07	0.11 ± 0.05	ns
	Total Biomass N stocks (Mg N ha^{-1})	0.0077 ± 0.004	0.001 ± 0.0008	<0.0001

subsidies of C and N) that mediate the C and N transfer and storage in connected seagrass ecosystems and with seagrass species that exist non-connected with other seagrasses (Huxham et al., 2018; Saavedra-Hortua et al., 2023).

Therefore, the main objective of this study is to i) assess the variation in sediment and plant traits, ii) quantify the C and N stocks, and iii) assess the contribution of various C sources to sediment C pool across *T. hemprichii* meadows. These *T. hemprichii* meadows are present with other seagrass species (hereafter non-connected) and are contrasted with meadows adjacent to mangroves (hereafter connected). These connected and non-connected meadows inhabit the tropical oligotrophic islands of the Andaman and Nicobar, India. The Andaman and Nicobar Islands of India harbor 10 out 16 seagrass species observed from the coast of India (Gole et al., 2024; Mishra et al., 2024). These islands provide a unique oligotrophic coastal setting, where seagrasses are present adjacent to mangroves (Mishra et al., 2021; Mishra and Apte, 2021). Despite an increase in scientific research on seagrasses in the last decade, there are significant knowledge gaps in seagrass research of India, most importantly in assessment of the climate change mitigation potential through blue carbon storage (Stankovic et al., 2023). Assessing the C and N stocks of *T. hemprichii* meadows, in this study will further enhance our understanding about the role of mangroves and other seagrass species in contributing to the climate change mitigation potential through C storage. We hypothesize that connected *T. hemprichii* meadows will store higher C and N stocks compared to non-connected *T. hemprichii* meadows due to higher inputs of matter and nutrients from mangroves.

2. Methods

2.1. Study sites

The tropical Andaman and Nicobar Islands (ANI) is located in the southeast coast of India in the Andaman Sea, in the Indian Ocean Region (Fig. 1). These islands of ANI and the surrounding coastal areas are considered oligotrophic due to absence of natural riverine inputs of organic matter and nutrients (Mishra and Farooq, 2025; Sahu et al., 2023), despite experiencing substantial rainfall 3000–3500 mm (Indian Meteorological Department, 2024). These tropical islands of ANI are inhabited by 10 out of 25 seagrass species of the Indian Ocean Region (Mishra et al., 2024).

For this study, three intertidal seagrass locations of ANI were selected; Swaraj Dweep (hereafter Havelock), Burmanallah and Haddo Bay (Figss. 1and 2) where *T. hemprichii* meadows were observed mixed with other seagrasses (hereafter non-connected). Similarly, three locations; Havelock, Saheed Dweep (hereafter Neil) and Burmanallah were selected for *T. hemprichii* meadows that were present adjacent to mangroves (hereafter connected) (Figs. 1 and 2). The connected *T. hemprichii* meadows were present at least 1500–2000 m away from the non-connected seagrass meadows. Both connected and non-connected sites exhibited a semi-diurnal tidal amplitude of 2.45 m (Mishra and Apte, 2020). The sampling from non-connected (along with other seagrasses) and connected meadows were collected during low tide at a depth of 0.3–0.5 m at each location during the dry season of ANI (April–May 2023).

2.2. Sediment sampling and processing

Ten replicate cores were collected using a PVC (polyvinyl chloride) corer (15 cm depth x 5 cm diameter) for non-connected and connected meadows at each location. The choice of 15 cm depth corer was based on previous literature review for our study locations (Mishra et al., 2021; Mishra and Apte, 2020), that indicated presence of intertidal coral-reef dominated habitats that prohibited standard sediment core collection of 1m depth recommended for blue carbon ecosystems (Howard et al., 2014). The sediment corer was pushed down to a depth of 10 cm as further depth achievement was impeded by the presence of rocky substrates or dead coral reefs (Mishra et al., 2023). The sediment cores were transferred into plastic zip lock bags, labelled and stored in dark boxes and transported to the laboratory. In the laboratory, each core was sectioned at 5 cm intervals and any live roots or debris were removed and oven dried at 60 °C for 48 h. The sediment dry bulk density (DBD; g cm^{-3}) was quantified by multiplying the sediment dry weight with the core volume (Howard et al., 2014). From these dried sediment sections, 5 g of sediment samples were acidified with 10 ml of hydrochloric acid (10 % HCl) and were heated for 2 h in an oven at 45 °C to remove carbonates and treated again with 10 ml of 30 % hydrogen peroxide (H_2O_2) for removal of any organic matter (Mishra and Farooq, 2025; Prajith et al., 2016). The resulting residue was oven dried and used to determine the sediment grain size distribution using a Laser Particle Size Analyzer (LPSA, Horiba, LA-950V2). The dried sediment samples were homogenized using a disc mill grinder (Retsch, RS200, USA) and stored for various analysis. Homogenized sediment samples of 5 g were combusted in a muffle furnace at 550 °C for 4.5 h to determine the sediment organic matter (OM %) content (Howard et al., 2014). From the remaining fraction of sediment samples, 0.30 mg of each replicate was

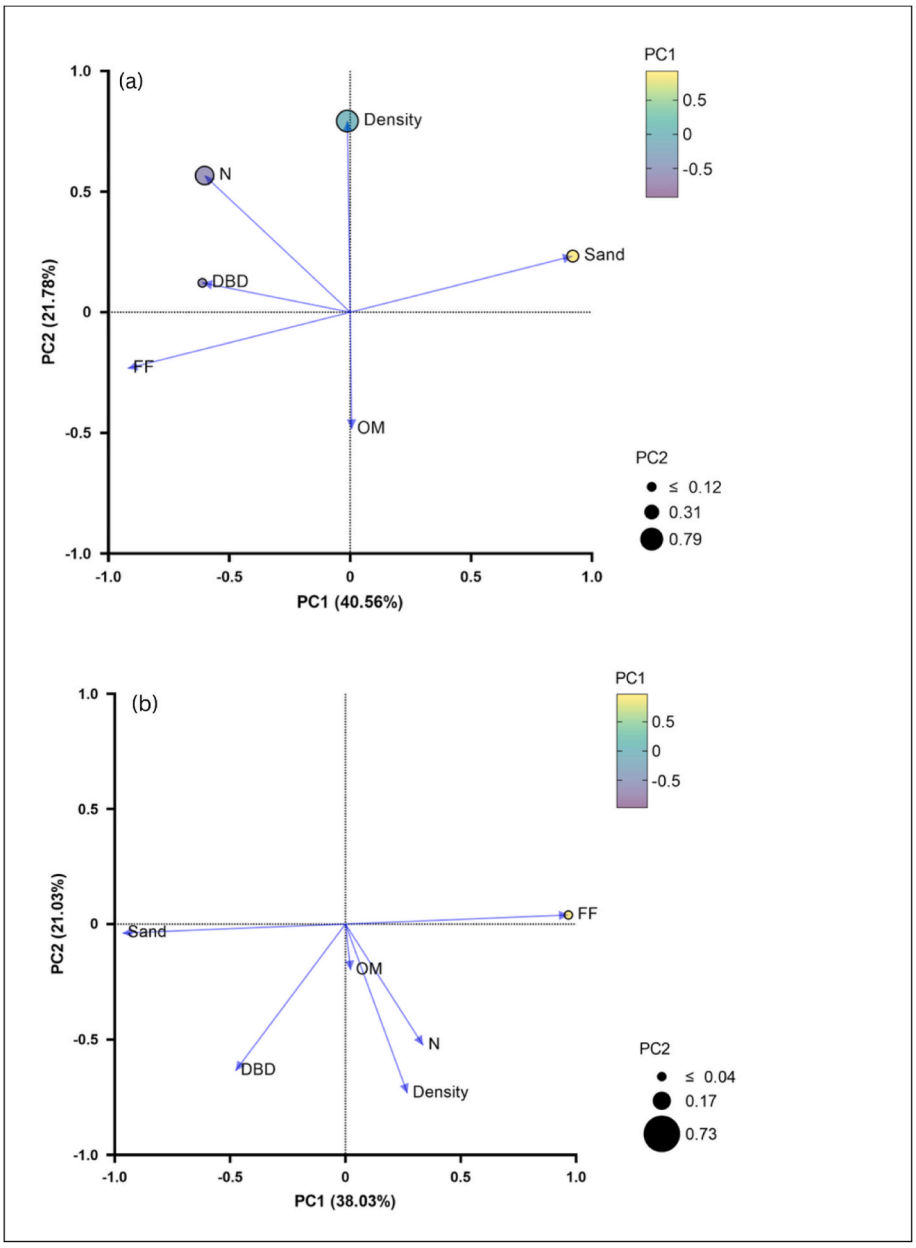

Fig. 3. Loadings of Principal Component Regression (PCR) analysis between sediment C stocks and other variables (Dry Bulk Density (DBD; g cm-3), Organic matter (OM%), nitrogen (N%), Fine fraction (FF%)) and *T. hemprichii* density across a) non-connected and b) connected meadows. The Principal Component (PC) contributions are presented in Supplementary Table S3.

prepared using tin capsules for analysis of total C and N and stable isotopes ratios of $\delta^{13}C$ and $\delta^{15}N$. Samples were analyzed in duplicate for total C (%), N (%), $\delta^{13}C$(‰) and $\delta^{15}N$ (‰) analysis using a Flask Elemental Analyzer coupled to a Delta V Isotope Ratio Mass Spectrometer (IRMS, Euro Vector, EA3028 EA-Nu). Precision (0.2 ‰) and calibrations were verified using in-house acetanilide standard (Iacet#1, $\delta^{13}C = -29.53$ ‰ and $\delta^{15}N = 1.18$ ‰). Vienna Pee Dee Belemnite (VPDB) and atmospheric air were used as isotope references for C and N respectively.

2.3. Stable isotope mixing modelling

Stable Isotope Mixing Models in R (SIMMR) based on the Bayesian frameworks of isotope mixing were utilized to estimate the contribution of various autochthonous and allochthonous sources of organic carbon to the sediment C pool of non-connected and connected *T. hemprichii* meadows (Phillips et al., 2005). The modelling employed 'simmr' and 'rjags' packages, utilizing the $\delta^{13}C$, $\delta^{15}N$ and C:N ratios as inputs, running 10,000 iterations via a Markov Chain Monte Carlo (MCMC) algorithm to maintain mass balance across isotopes (Parnell et al., 2013) and the results are presented as boxplots with 50 % confidence intervals. The MCMC technique evaluates the probability of source proportions in the samples while accounting for uncertainties such as isotopic, diagenetic fractionation changes, residual error etc. The 'simmr' package allows the incorporation of $\delta^{13}C$ uncertainty into mixing models, while producing a Bayesian quantification of the most likely source contributors with n+1 sources when matching against an isotope (Parnell et al., 2013). In this study, $\delta^{13}C$, $\delta^{15}N$ and C:N ratios were measured for *T. hemprichii*, along with other seagrasses (*Halodule uninervis*, *Halophila ovalis*, *Enhalus acoroides*, *Halophila beccarii*, *Cymodoceae rotundata*) from non-connected meadows and mangrove; *Bruguiera* spp., and *Rhizophora apiculata* leaves (Supplementary Table S1) and sediment samples to

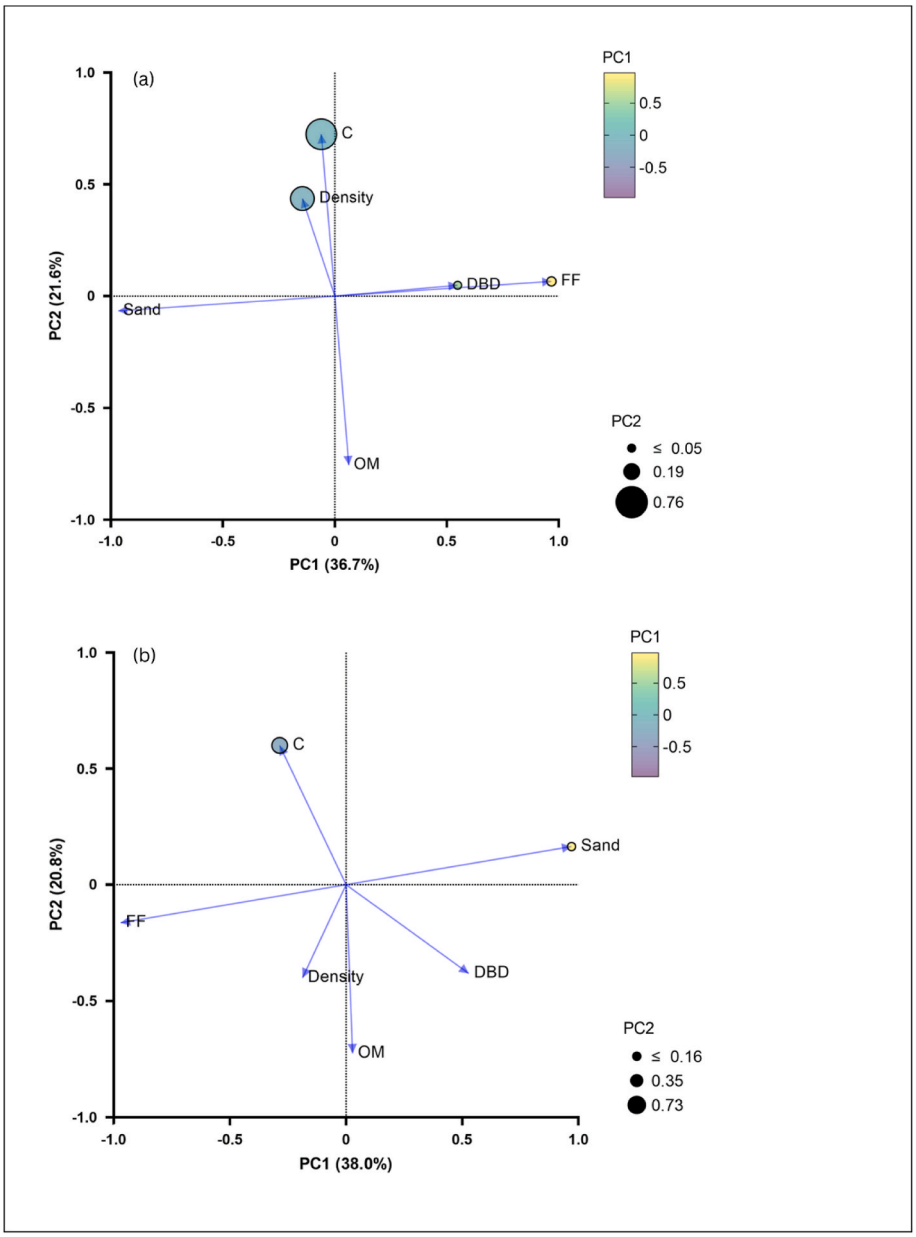

Fig. 4. Loadings of Principal Component Regression (PCR) analysis between sediment N stocks and other variables (Dry Bulk Density (DBD; g cm-3), Organic matter (OM%), nitrogen (N%), Fine fraction (FF%)) and *T. hemprichii* density across a) non-connected seagrass and b) connected meadows. The Principal Component (PC) contributions are presented in Supplementary Table S3.

avoid overlaps of $\delta^{13}C$ sources between seagrass and mangroves (Bouillon et al., 2008; Fry and Ewel, 2003). The isotopic and C:N ratios of the end members; particulate organic matter (POM) of marine origin ($\delta^{13}C$; -20.3 ± 1.31 ‰, $\delta^{15}N$; 4.7 ± 0.14 ‰ and C: N; 16.3 ± 4.38 %) for our study locations were derived from literature of local studies (Ramaswamy et al., 2008; Sarkar et al., 2024).

2.4. Seagrass sampling and analysis

10 random replicate quadrats (20 cm × 20 cm) were collected at both non-connected and connected seagrass meadows within a depth of 0.3–0.5 m during low tide. From the quadrat, the seagrass samples were dug out with a hand-held shovel up to 10 cm depth, rinsed carefully in the field with seawater, stored in zip-lock bags and transported to the laboratory. In the laboratory, the plant samples were washed with deionized water to remove any debris, and organisms attached to the leaves were scrapped off with a glass slide and stored for biomass analysis. The density of *T. hemprichii* from each sample was calculated by counting the number of individual shoots. Then the biomass was divided into AG-biomass (leaves) and BG-biomass (shoots + roots) and oven dried at 60 °C for 48 h. Dried biomass samples were homogenized and analyzed for total C, N $\delta^{13}C$ and $\delta^{15}N$ following the same methods described for sediment samples (*see* section 2.3).

2.5. Statistics

An unpaired *t*-test was used to check the statistical significance ($p < 0.05$) for sediment and biomass traits of *T. hemprichii* across non-connected and connected meadows. All data was pre-checked for homogeneity of variance and normality using Levene's and Shapiro-Wilk tests. Principal Component Regression (PCR) was used to check the effects of various sediment traits (sand, fine fraction (FF), DBD, N, OM) and plant density on sediment C stocks. All statistical tests were conducted at significance level $p < 0.05$ and presented as mean and

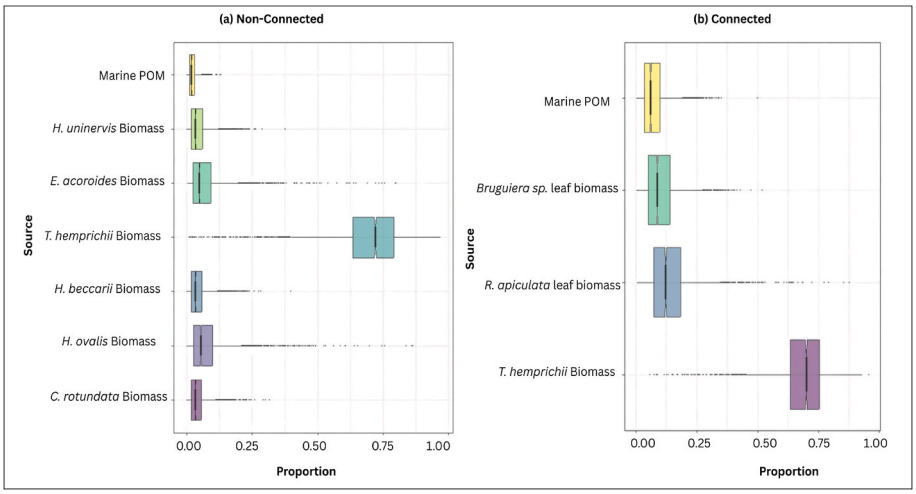

Fig. 5. Box plots of SIMMR mixing model results displaying the average source contribution to sediment carbon pool in the non-connected and connected meadows of *T. hemprichii* (Th) in ANI, India. Lines inside the box plots represent mean values. POM (Particulate organic matter). 50 % confidence intervals are presented in Supplementary Table S4.

standard deviation (SD). GraphPad Prism (ver. 10.4.1) was used for all statistical analysis and graph making. SIMMR modelling was analyzed using R software.

3. Results

3.1. Influence of connectivity on sediment traits

Significant differences were observed in the sediment characteristics between non-connected and connected meadows. In general, the sand content (unpaired *t*-test; t, df (2.15, 68), $p < 0.01$), fine fraction (t, df (2.15, 68), $p < 0.01$), organic matter (OM; t, df (2.23, 68), $p < 0.01$), total carbon (C; t, df (4.21, 68), $p < 0.0001$), total nitrogen (N; t, df (10.64, 68), $p < 0.0001$), $\delta^{13}C$ (t, df (2.86, 28), $p < 0.0001$), $\delta^{15}N$ (t, df (15.17, 28), $p < 0.0001$), C stocks (t, df (2.27, 68), $p < 0.05$) and N stocks (t, df (6.60, 68), $p < 0.0001$), all varied significantly (Table 1, Supplementary Table S2). The mean sand content of non-connected meadows was 1.2-fold higher, whereas, the finer sediment fraction (clay + silt) was 1.3-fold lower than connected meadows. The lower fine fraction led to 1.2-fold reduced sediment OM content in non-connected meadows compared to connected meadows (Table 1).

In non-connected meadows the sediment C was 1.5-fold lower than connected meadows, whereas the sediment N in non-connected meadows was 3.7-fold higher than connected meadows. Interestingly, the sediment $\delta^{13}C$ values in non-connected meadows were more enriched compared to the more depleted $\delta^{13}C$ values of connected meadows. Similar trend has been observed in sediment total N, where $\delta^{15}N$ values in non-connected meadows were more enriched compared to the $\delta^{15}N$ values of the connected meadows (Table 1). The sediment C stocks of non-connected meadows were 1.3-fold lower than connected meadows, whereas the sediment N stocks of non-connected meadows were 4.1-fold higher than connected meadows (Table 1).

The influence of various sediment traits (i.e., OM, DBD, fine fraction and N content) and plant density on sediment C stocks in non-connected meadows were depicted through Principal Component (PC) Regression analysis. The sediment OM, sand and plant density contributed towards 40.56 % of the variation in PC1 and PC2 contributed 21.78 % of the variation influenced by sediment DBD, fine fraction and N content (Fig. 3, Supplementary Table S3). However, for sediment N stocks no significant effects of sediment and plant traits were observed across non-connected and connected meadows (Fig. 4, Supplementary Table S3).

3.2. Influence of connectivity on seagrass traits

Significant differences were observed for *T. hemprichii* shoot (t, df (5.26, 68), $p < 0.0001$) and apex (t, df (3.39, 68), $p < 0.0001$) density across the non-connected and connected meadows (Table 1, Supplementary Table S2). The shoot density and apex density of *T. hemprichii* in non-connected meadows were in general 1.4-fold higher than in the connected meadows. The total biomass, leaf C content, $\delta^{13}C$ values and biomass C stocks of *T. hemprichii* across non-connected and connected meadows were not significantly different (Table 1). Contrastingly, significant differences were observed for the leaf N content (t, df (15.23, 28), $p < 0.0001$), $\delta^{15}N$ (t, df (14.34, 28), $p < 0.0001$) and biomass N stocks (t, df (6.25, 68), $p < 0.0001$) across non-connected and connected meadows. The leaf N, and biomass N stocks in non-connected meadows was 3.3-fold and 7-fold higher than the connected meadows. However, the values of $\delta^{15}N$ in *T. hemprichii* biomass of non-connected meadows was more enriched compared to the connected meadows (Table 1).

3.3. Influence of connectivity on C contribution to sediment C pool

Stable isotope mixing modelling showed that *T. hemprichii* biomass contributed the highest to the sediment C pool in non-connected seagrass meadows followed by *H. ovalis* biomass (Fig. 5a, See Supplementary S4 & S5). In connected meadows, *T. hemprichii* biomass contributed the highest proportion to the sediment C pool followed by mangrove leaf biomass of *R. apiculata* and *Bruguiera* sp., (Fig. 5b–Supplementary Tables S4 and S5).

4. Discussion

In this study we estimated the C and N stocks of non-connected and connected meadows of *T. hemprichii* from the coast of Andaman and Nicobar Islands (ANI) of India, with first time quantification of seagrass N stocks in ANI and India. However, globally, seagrass N stocks have been quantified for various seagrass species such as *Zostera* spp., *Posidonia* spp., *Heterozostera tasmanica, and Amphibolis* spp. among others, but not for *T. hemprichii* (Saavedra-Hortua et al., 2023; Casal-Porras et al., 2022; Apostolaki et al., 2024; Moksnes et al., 2021; Santos et al., 2019; Kindeberg et al., 2018). Recent studies have showcased that seagrass ecosystems (both non-connected or mono-specific) being adjacent to mangroves benefit from the cross-habitat transfer of OM and nutrients via daily tidal influx resulting in better ecological functioning and ecosystem services, particularly C storage (Mishra et al., 2023;

Table 2
Comparisons by various locations of India for average ± SD or range of sediment organic carbon (C_{org} %), dry bulk density (DBD; g cm^{-3}) and C stocks (Mg C ha^{-1}; up to 30 cm and 1m depth). *Connected seagrass include seagrass habitats adjacent to mangroves. # This study.

Sl. no	Location (Reference)	Habitat	C_{org} (%)	DBD (g cm^{-3})	C stock (Mg C ha^{-1}) (up to 30 cm depth)	Stock (Mg C ha^{-1}) (1 m depth)
1	Andaman and Nicobar Islands#	#Non-connected Seagrass	2.03 ± 0.50	0.12 ± 0.05	2.61 ± 1.48	–
		Connected*	3.02 ± 0.94	0.16 ± 0.06	3.50 ± 1.78	–
2	Andaman and Nicobar Islands (Mishra et al., 2023)	Mono-specific	1.15 ± 0.25	0.83 ± 0.11	9.40 ± 1.38	–
		Connected*	2.08 ± 0.23	0.75 ± 0.23	18.87 ± 4.36	–
3	Chilika lagoon, Odisha (Kaladharan et al., 2021)	Non-connected seagrass	0.395	1.67	2.01 ± 0.67	–
	Pulicat lake, Tamil Nadu (Kaladharan et al., 2021)	Non-connected seagrass	0.473	1.09	0.998 ± 0.41	–
4	Gulf of Mannar, Tamil Nadu (Kaladharan et al., 2020)	Non-connected Seagrass	0.09 ± 0.014		3.45	–
	Palk Bay, Tamil Nadu (Kaladharan et al., 2020)	Non-connected Seagrass	0.71 ± 0.08		3.88	–
5	Gulf of Mannar, Tamil Nadu (Ghosh et al., 2016)	Non-connected Seagrass	1.16 ± 0.33	–	–	–
6	Chilika lagoon, Odisha (Ganguly et al., 2017)	Non-connected Seagrass	0.68-0.93	–	–	127.08
	Palk Bay, Tamil Nadu (Ganguly et al., 2017)	Non-connected seagrass	0.97-1.10	–	–	159.53
7	Lakshadweep Islands (Kaladharan et al., 2022)	Non-connected Seagrass	0.18-0.34	0.91-1.11	0.37-0.97	–
8	Pulicat lake, Andhra Pradesh (Murugan et al., 2024)	Non-connected Seagrass	–	–	–	1.29-11.9

Asplund et al., 2021a; Saavedra-Hortua et al., 2023). In this study, we observed similar patterns, where connected meadows exhibited increased sediment OM and total C content resulting in increased sediment C stocks compared to non-connected meadows. The sediment OM and total C content observed in this study are lower than the previously reported OM content, but was observed with higher C content than previously reported in connected meadows of ANI (Mishra et al., 2023; Sachithanandam et al., 2020). This variation indicates the dynamic nature of surface erosion of sediment OM and leading to lack of fine fraction of sediment such as silt or clay that helps in retaining the OM. Additionally, the connected *T. hemprichii* meadows have colonized dead coral reef ecosystems after 2004 Indian Ocean Tsunami, that due to coastal upliftment have high coral reef derived sandy conditions (Ghadamode et al., 2024). This limits the long-term accumulation of sediment OM and C in these ecosystems. Furthermore, these tropical islands lack natural riverine inflow, which in general helps in long-term influx of finer sediment into mangroves and mangrove connected seagrass meadows (Mishra and Farooq, 2023).

Similarly, the sediment OM and total C content of the non-connected *T. hemprichii* meadows compared with previous mono-specific meadows are also higher, indicating the positive influence of presence of various dense seagrass meadows with *T. hemprichii*. Similar influence of the presence of non-connected seagrass meadows on sediment OM, total C content and C stocks has been observed for *T. hemprichii* meadows mixed with *Cymodoceae rotundata*, *Thalassodendron ciliatum*, and *Enhalus acoroides* from the coast of Madagascar (Asplund et al., 2021b), from the coast of Australia with non-connected seagrass species of *Cymodoceae* spp., *Posidonia* spp. and *Syringodium* spp. (Mazarrasa et al., 2018b) and from the coast of Kenya for *C. rotundata*, *Cymodoceae serrulata*, *E. acoroides* and *T. ciliatum* (Juma et al., 2020).

The sediment C stocks observed in this study in the non-connected and connected meadows were significantly lower compared to previous studies from ANI for mono-specific and connected meadows (Table 2). This difference is a result of loss of sediment OM and total C during the wet season of ANI, where large scale freshwater influx happens for the shallow intertidal seagrass meadows. The sandy environment (>50 %) and coral reef-derived coarse sand further reduce the potential for long-term OM and C accumulation (Mishra et al., 2021, 2023; Gole et al., 2023). Nevertheless, the sediment C stocks of this study of both non-connected and connected meadows were comparable to or higher than previously reported seagrass C stocks of surficial sediment (up to 30 cm depth) from non-connected meadows of India's coast (Table 2). However, the C stocks in sediment of both non-connected and connected meadows of *T. hemprichii* was significantly lower than non-connected seagrass meadows of the Chilika lagoon, where deeper cores (>50 cm) revealed higher C storage in silty, OM-rich sediments (Ganguly et al., 2017).

Connectivity with mangroves did not significantly influence the seagrass traits, i.e., shoot and apex densities, primarily due to the lack of nutrients in the mangrove ecosystems of our study locations (Mishra et al., 2024; Sahu et al., 2023; Mishra and Farooq, 2023). However, non-connected meadows of *T. hemprichii* received higher N input from local anthropogenic influx, resulting in higher sediment N content. The anthropogenic nature of the sediment N input is evident from the high $\delta^{15}N$ values observed in non-connected seagrass meadows compared to the connected meadows. This external anthropogenic N input may have benefited the *T. hemprichii* meadows in increasing their shoot and apex densities, which has been previously observed from our study locations, whereas the shoot and apex densities of the connected meadows are within the range of *T. hemprichii* density reported for connected meadows (Mishra et al., 2023, 2025b; Mishra and Farooq, 2023). This indicates the oligotrophic nature of these island ecosystems, where seagrass ecosystems are generally N limited, and short-term spikes in the dry season benefits the intertidal meadows that are in close contact with the locations of anthropogenic input (Mishra and Apte, 2020).

This is the first study to assess the contribution of various allochthonous and autochthonous sources to sediment C pool of seagrass ecosystems of India using stable isotopes of C and N. However, in general, the use of stable isotopes for carbon stock studies on mangrove ecosystems of ANI, lack exploring the influence of connectivity on sediment C stocks (Mishra et al., 2025c; Ragavan et al., 2023). In this study, a positive influence of seascape connectivity with mangroves is observed, even though with a relatively low contribution to the sediment C pool of *T. hemprichii* meadows. The highest contribution came from *T. hemprichii* biomass, which highlights that the sediment C storage in these oligotrophic islands is primarily of autochthonous origin and driven by seagrass derived carbon sources. Similarly, in the non-connected meadows of *T. hemprichii*, the seagrass-derived C contribution to the sediment C pool was similarly higher. Interestingly the marine POM contribution to the sediment C pool was low in both connected and non-connected meadows, despite the higher N input in *T. hemprichii* non-connected

meadows. Our findings of high contribution of seagrass derived C to the sediment C pool aligns with studies from similar tropical islands of Maldives, where seagrass species (*T. hemprichii, T. ciliatum, Halodule pinifolia, S. isoetifolium and C. rotundata*) contributed highly to the sediment C pool (Macreadie et al., 2024).

This study highlights that seagrass ecosystems of tropical oligotrophic islands have low sediment C stocks compared to OM-rich silty and clay sediments where land based riverine input contributes significantly to the sediment C pool. However, we have only sampled three islands of the ANI, which constitutes more than 5000 islands. Future research focused on both intertidal and deep seagrass (20 m depth) meadows (Bayyana et al., 2020) of the islands is essential to assess the blue carbon storage and green-house gas emissions of these oligotrophic island ecosystems and quantify their climate change mitigation potential. These assessments can lead to inclusion of seagrass ecosystems of ANI in India's Nationally Determined Contributions and National Action Plan on Climate Change.

CRediT authorship contribution statement

Amrit Kumar Mishra: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Visualization, Validation, Writing – review & editing. **Syed Hilal Farooq:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecss.2025.109587.

Data availability

Data will be made available on request.

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