Journal of Coastal Conservation (2022) 26:20
https://doi.org/10.1007/s11852-022-00863-6

Diversity of seagrasses and site-specific strategy for their restoration in Gulf of Kachchh Marine National Park—Gujarat, India

D. Adhavan[1] · **R. Chandran**[2] · **K. Sivakumar**[3]

Received: 24 December 2020 / Revised: 24 March 2022 / Accepted: 20 April 2022

Abstract

The Gulf of Kachchh (GoK) is diversified with various marine habitats, influenced by semi-diurnal tidal amplitude and heavy sedimentation. Seagrass is one of the key habitats in GoK with the predominant diversity of *Halophila ovalis, Halodule uninervis,* and *Thalassia hemprichii*. The seagrass is subjected to be at risk than any other habitats due to natural and human impacts. Strategies need to be developed to conserve seagrass patches of inhospitable environments like GoK, which demands the present feasibility study on seagrass restoration. In the present study, the seagrass habitats of the GoK were assessed in Pirotan, Narara, and Mithapur reef areas. *Halophila ovalis* showed the most extensive coverage in all the studied sites during the study period ($62.11 \pm 5.60/m^2$ in Pirotan; $60.70 \pm 7.24/m^2$ in Mithapur and $59.32 \pm 5.45/m^2$ in Narara sites). Likewise, *Thalassia hemprichii* showed the least cover in all the three studied sites ($25 \pm 6.28/m^2$ at Narara; $28.93 \pm 3.54/m^2$ in Pirotan and $31.78 \pm 4.16/m^2$ in Mithapur sites). Site-specific strategies have been attempted to develop a successful seagrass restoration nursery for *Ha. ovalis* and *H. uninervis* in the GoK region. To restore the seagrass species, vegetative sprigs were planted using the staple method. To increase the stability, the sprigs were later planted by attaching them within the iron frame (1 m x 1 m size) with the support of metallic mesh. The water quality and physical property of the restoration sites were documented. Two potential seagrass meadows were also identified along the Marine National Park (MNP) which can act as donor sites for restoration along the GoK in future.

Keywords GoK · Seagrass · Restoration · Nursery · *Halophila* · *Holodule*

Introduction

Gulf of Kachchh (GoK) located on the northwest coast of India represents some of the extreme northerly distribution limits of reef habitat in the Indo-Pacific region (Satyanarayana and Ramakrishna 2009). Their isolation in a sub-tropical location, possessing an arid climate with semi-diurnal tidal amplitude, and heavy sedimentation rate are the factors that make the Gulf a 'hyper-normal' environment for the inhabiting biota (Michael et al. 2009). The southern margin of the Gulf is fringed by a diverse assemblage of coral reefs, mangroves, seagrass, seaweeds, and it is one of the most productive and diversified habitats along the north-west coast of India (Nair 2002). Comprehending the importance of preserving these ecosystems in the Gulf, Govt. of India declared this area as Marine National Park & Sanctuary (MNP&S) and it is conserved under CRZ Category-I protected area (Nair 2002; Singh 2003; Adhavan et al. 2014).

The seagrass ecosystem is one of the key components of the Gulf of Kachchh region. Although seagrasses are among the most productive ecosystem in the world, they are the least studied critical component of the marine habitats in the Gulf of Kachchh region (Kamboj 2014). Seagrass shelters coastal waters and perform an array of vital ecological functions in marine ecosystems. The seagrass beds serve as an important feeding and nursery ground for a variety of commercial fishes, they act as a food source for threatened fauna like sea turtles and dugong (Johnstone 1978; Lanyon et al. 1989), and as a source of nutrients to the coastal community through detrital food chains. The seagrass ecosystem in the Gulf of Kachchh is reported to be under threat than

✉ D. Adhavan
adhavmarine@gmail.com

1 Center for Climate Change Studies, Sathyabama Institute of Science and Technology, Chennai 600119, India

2 Zoological Survey of India - Field Station, Forest Campus, "Van Sankul", Jamnagar, Gujarat 361001, India

3 Wildlife Institute of India, P.O. 18, Chandrabani, Dehradun 248001, India

Published online: 13 May 2022

any other marine habitat, due to stronger anthropogenic pressure and climate change (Nobi et al. 2011; Thangaradjou and Bhatt 2018). The common seagrass species recorded in the Gulf are *Halophila ovalis*, *H. beccarii, Halodule uninervis*, *Thalassia hemprichii* and *Zostera marina* (SAC 2010). Among them, species like *Halophila ovalis, Halodule uninervis,* and *Thalassia hemprichii* were recorded to be more predominant in the Gulf of the Kachchh region. Thangaradjou and Bhatt (2018), reported eight species of seagrass from the Gujarat coast which stands next to Lakshadweep that harbours ten species. In this regard, a recent study reveals the occurrence of *Halophila decipiens* as scattered meadows from Beyt Dwarka and Bhaidar reefs area (WII 2019). However, Singh et al. (2004) recorded sparse distribution of seagrass at Paga Reef, Chandri Reef, Noru Reef, Bhural Chank Reef, Kalubhar Reef, Narara Reef, Boria Reef, Mangunda Reef, Goose Reef and Pirotan Island, and low-density seagrass meadows around Meetha Chusna Island, Bhaidar Island, Chank Island, Ajad Island, Jindra Island, Chhad Island and Poshitra Reef.

The marine habitats of the Gulf are always under pressure due to heavy water current, macrotidal regimes, unstable substrate, and increased sedimentation rate due to the flow of the Indus River and other water channels (Roger 1990; Ramaswamy et al. 2007; Nayruti et al 2011; Chatterjee and Ray 2017). Moreover, industrialization, pollution, coastal development, unsustainable fishing practices, elevated sea surface temperature and sea-level rise are the other factors that affect the ecosystem structure and function in the GoK (Dixit et al. 2010; Adhavan et al. 2014). Nearly, 65% of seagrass cover loss was recorded since 2008 in the GoK due to increased sedimentation owing to coastal development, alteration, and natural pressure. This led to substantial concern about the health of the seagrass ecosystem (Bjork et al. 2008). Loss of seagrass habitat and evidence of ecological imbalance was the impetus for investigating the restoration of seagrass habitat in the Gulf of Kachchh region. The primary objective of this work is to develop a nursery to restore the seagrass habitats in the GoK area by following suitable technologies. The seagrass restoration process and nursery development are challenging in the GoK area due to its dynamicity and unstable substrate. The seagrass restoration in India is still in the emerging stage, there are only very few experimental activities have been attempted (Edward et al. 2019). Globally, several techniques have been attempted to facilitate the restoration and recovery of seagrass meadows at the sites where they were recently disturbed (Paling et al. 2009; Cunha et al. 2012). However, the success rate varies at different locations (Fonseca 1992; Gordon 1996; Seddon 2004). Transplanting vegetative rhizome is the commonly used approach to establish seagrass at former sites or at new sites to balance losses associated with recommended activities (Fonseca et al. 1998; Matheson et al. 2016). There was a reasonably extensive seagrass cover at the GoK MNP area, but a significant percentage of seagrass cover has been lost due to coastal development and pollution (Bjork et al. 2008; Kamboj 2014). On other hand, natural threats such as climate change, sea surface temperature (SST), increased intensity and frequency of storms and extreme weather events, and freshwater intrusion have also pushed the seagrass meadows to further risk (IUCN 2007). These unprecedented threats have necessitated the need for seagrass restoration as a management tool in the GoK area. The present study describes a site-specific, modified methodology, adapted to develop a successful seagrass restoration nursery for sedimented and current impacted marine habitats like the Gulf of Kachchh.

Materials and method

Ecological monitoring of seagrass

Seagrass species distribution was studied along the Gulf of Kachchh coast at Pirotan (22°35′36.91 N 069°57′40.15E), Narara (22° 28′ 35.69" N 069°43′ 12.90" E) and Mithapur (22°27′26.53 N 069°01′24.12E) as a part of the Integrated Coastal Zone Management Project (ICZMP) during 2013–2016 and Rufford’s small grant seagrass restoration project 2017–2018. The seagrass distribution was classified as sparse, medium dense and highly dense based on their density. The seagrass diversity was estimated using the random quadrant method (English et al. 1997) at all classified sites owing to irregularities of the topography. Water quality was assessed at all three sites using Hydrolab-ES5, multi parameters kit during 2017 to understand the correlations of water quality parameters and seagrass species distribution (Fig. 1).

Nursery sites

A pilot study was carried out to select suitable donor and nursery (recipient) sites for seagrass restoration. An intensive survey was carried out at three spatially distinct sites i.e., Pirotan, Narara and Mithapur during the ecological monitoring surveys. Finally, the Mithapur area was selected for the experimental purpose owing to the recent disturbance caused to the seagrass ecosystem by anthropogenic and natural pressures. The sites were selected near a massive reef structure and dense seagrass patches. The sites were shallow, and the intensity of the water current was found to be reduced due to the shading effect of nearby reef structures.

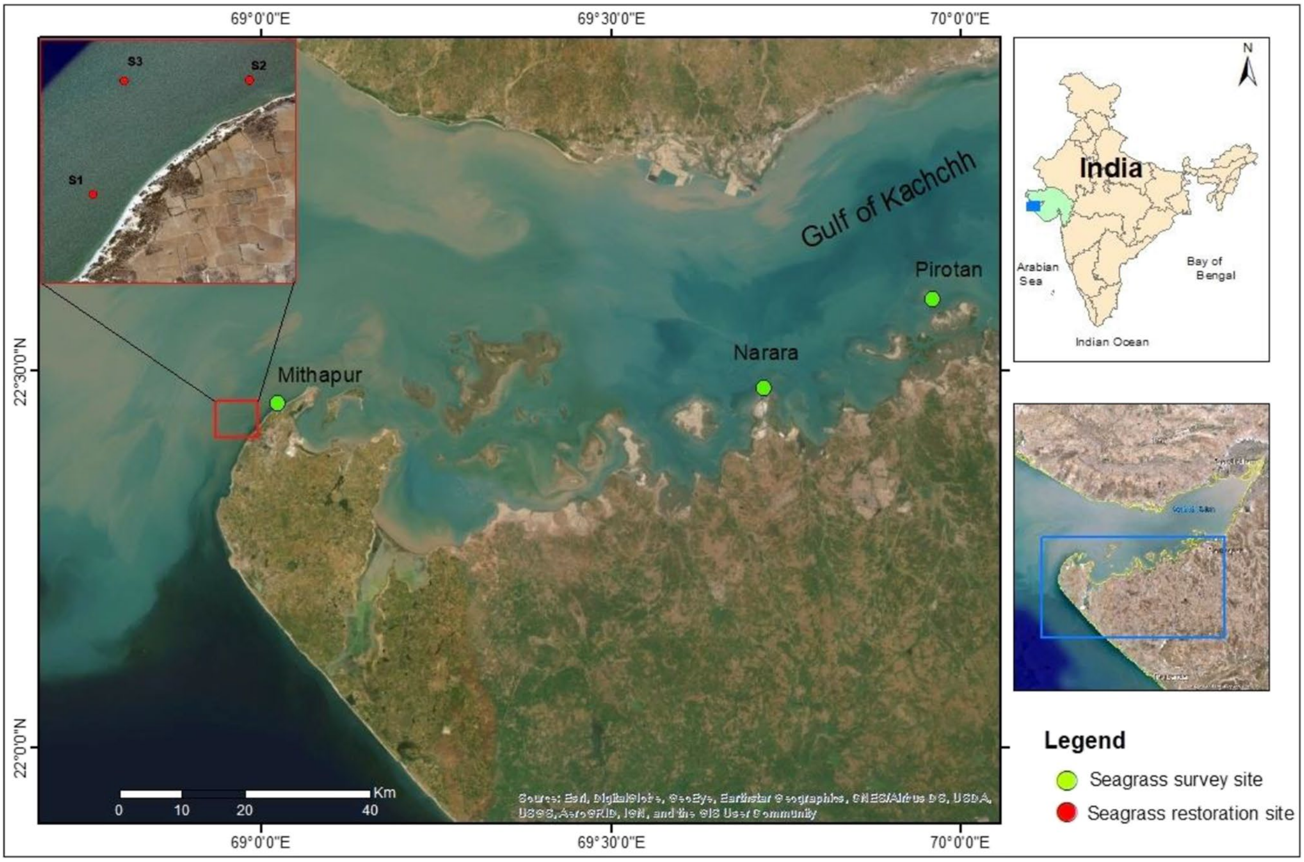

Fig. 1 Map showing restoration and survey sites

Restoration technique

Seagrass nursery activities were carried out in the selected sites during the period between 2017–2018. Vegetative rhizomes from the nearby donor sites were extracted by fanning overlying silts to expose the rhizomes. Initially, plantation experimentation was performed to ascertain the most feasible technique in the GoK area, including the staple method as described by Fonseca et al. 1998. The vegetative parts of the seagrass were manually collected in a mesh bag at a depth of 3 to 4 m by SCUBA diving. Then the plants were attached to a metallic staple by inserting the root-rhizome portion under the silt. The clip was secured around the plants at the basal meristem so that the leaves can extend from under the string up into the water column when planted. A total of 200 seagrass sprigs were transplanted at each mesh frame (1 m X 1 m sized). After two weeks of the plantation, the stability of planted seagrass was assessed. The *in-situ* experiment was carried out in triplicate.

Seagrass nursery

The number of planting methods has been adapted at different regions for seagrass restoration including seeding, stapling, use of anchored and unanchored sprigs, plugs, peat pots, and transplantation of individual mature plants as suggested by Phillips (1980), Fonseca (1994), and Fonseca et al. (1998), the fertilization of transplants to accelerate growth and bed coalescence is described by Fonseca et al. (1987, 1998) and Kenworthy and Fonseca (1992). Traditional seagrass restoration guideline recommends careful site selection, i.e., a sheltered location with an adequate light environment. In the present study, the methodology was developed based on the bottom topography, seagrass distribution and environmental parameters of the Mithapur region. The sea surface temperature (SST) varied from 22.5 (Jan) to 29.4 °C (June) during the restoration activities carried out and this is the optimum temperature for the seagrass ecosystem (Mc Millan 1984). Likewise, the salinity of the site varied from 30.6 to 37.7ppt. Light availability is one of the most important determinants of seagrass bed health. Generally, seagrass requires 15 to 25 per cent of light availability at the water's surface. During the present study, turbidity at the restoration site was recorded from 0.375 to 0.427 V.

The depth of the selected sites for the nursery activities was 2.5 m to 1.25 m during high-tides and low-tides, respectively. To sow the vegetative seagrass sprigs firmly, we have modified the staple method with iron frames. In this method, three frames (1 m x 1 m) with mesh and boulders at the four corners (Fig. 2a) were designed. To increase the stability, collected sprigs were planted by attaching with the help of a metallic pin hook within the iron frame (1 m x 1 m size) with the support of metallic mesh. The plantation was carried out on consecutive days for a week during low tide. All the plots were acclimatized overnight and monitored regularly in successive weeks.

Result & discussion

The seagrass covers of the studied sites in the Gulf of Kachchh is represented by *Halophila ovalis, Halodule uninervis,* and *Thalassia hemprichii*. The species diversity of seagrass is generally found to be predominant during the post-monsoon season (November to February). The percentage cover of the species, *Halophila ovalis* was observed healthy and dominant in all the studied sites during the study period (Fig. 3). Whereas *Holodule uninervis* and *Thalassia hemprichii* were found to be disturbed and completely vanished in some places during the pre-monsoon season.

Water quality analysis

The water quality analysis reveals the turbidity was fluctuating at all the study areas. The turbidity was less during post-monsoon, gradually increasing during summer and pre-monsoon and reduced during post-monsoon. The increasing turbidity would reduce light accessibility to seagrasses. It was also revealed that the dissolved oxygen (DO) was higher during post-monsoon, gradually decreasing during summer and pre-monsoon, and fluctuating during monsoon. This will signify the factors controlling the occurrence of seagrasses (Table 1). However, compared to Narara and Pirotan, Mithapur has less impact of limiting factors for the occurrence of seagrass.

Seagrass diversity and ecological relationship

The turbidity and dissolved oxygen were a few of the major factors that support the seagrass distribution. The relationship between an environmental factor and seagrass distribution are given in Table 2. Dissolved oxygen revealed a positive correlation with all three species of seagrasses while turbidity showed a negative correlation with the seagrasses from all the sites of the study area. All the seagrass species showed a positive correlation with each other, revealing, no species is dominant over the other. However, from these

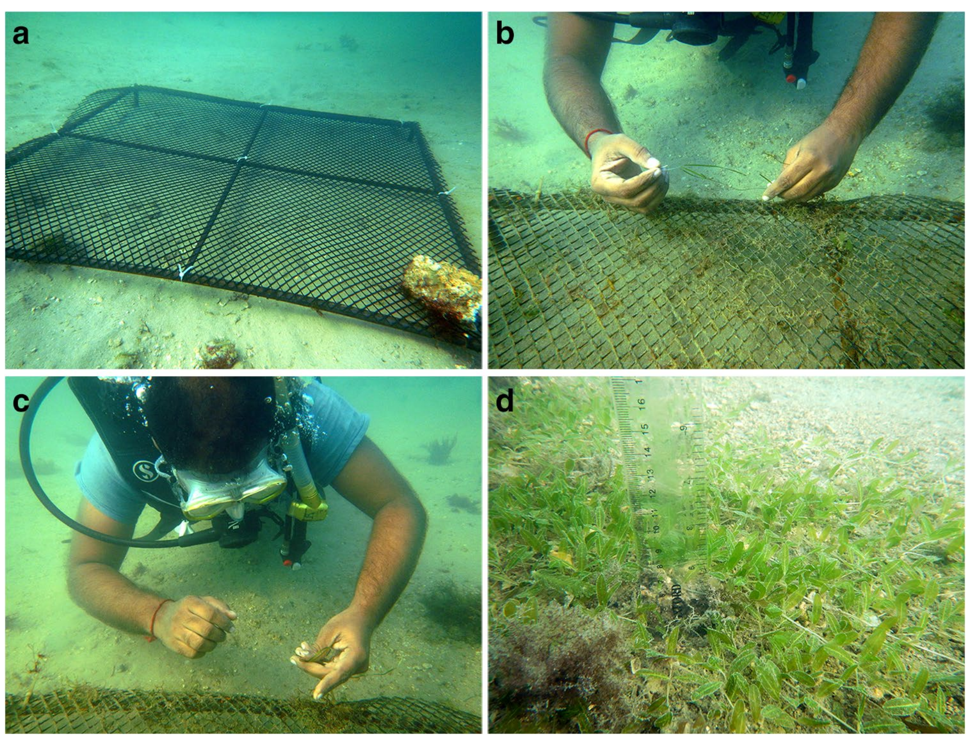

Fig. 2 **a** Mesh with the iron frame; **b**-**c** Planting seagrass sprigs within the frame; **d** stabilized seagrass after restoration

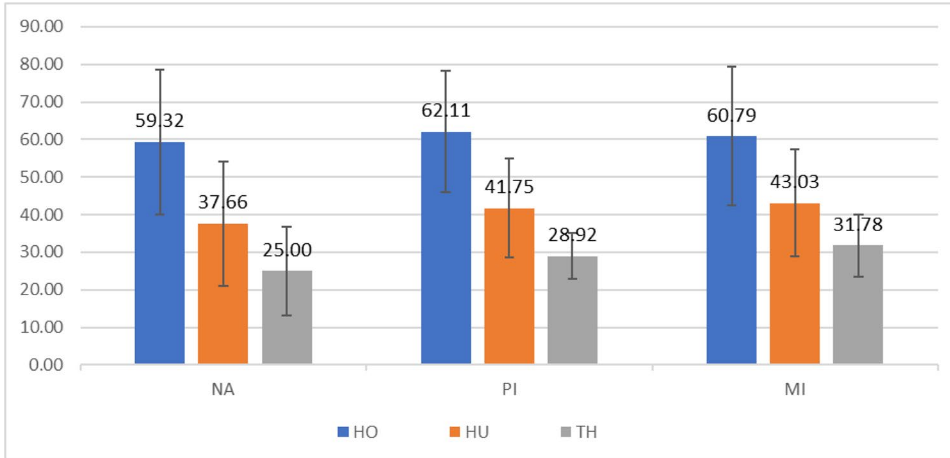

Fig. 3 Distribution of Seagrass in GoK area. (NA – Narara, PI – Pirotan, MI – Mithapur; HO –*Halophila ovalis*, HU –*Holodule uninervis*, and TH –*Thalassia hemprichii*

correlations, turbidity was found to be one of the prime limiting factors for seagrass diversity in the Gulf of Kachchh area.

The seagrass species *Halodule uninervis* was found to be stabilized within the frame from the first week onwards. The transplants were not washed away by the current and water movement due to the firm attachment of the rhizome in the mesh with the help of a metallic clip. The nursery site has been observed to support diverse fishes augmentation as well. Among the planted seagrass species, *Halophila ovalis* showed maximum stability in all the studied sites. This is perhaps due to the structural attributes of the seagrass species. *Ha. ovalis* has oval-shaped short leaves and short petioles that holds the seagrass close to the ground level within the frame, this may help them to escape the intensity of the water current. Whereas *Halodule uninervis* has a wide and longleaf blade with a vertical rhizome, which may make them vulnerable to the intensity of the water current at the studied site during the experiment period. In the experimental frames, loss of seagrass sprigs was observed more during the first month of plantation for both the species 21.34% for *Ha. ovalis* and 35.36 for *Ho. uninervis*. Afterwards, the loss % of the sprigs reduced gradually and it stabilized successfully during the subsequent months (Table 3). In the Gulf of Kachchh, sheltered sites with less direct current influence supported a good seagrass cover. As a part of the present study to explore such shaded sites, Armabada lake (22°26′25.88 N; 069°02′40.59E) and tidally influenced cement tanks constructed and abandoned by Gujarat State Fertiliser and Chemical Ltd., (22°25′47.96 N; 069°49′33.58E), Sikka was identified as potential reserves and they can act as natural nurseries for seagrasses along the Gulf of Kachchh Marine National Park. These sites were observed with a maximum water depth up to 2 m and supported a good density of *Ha. ovalis* seagrass cover (avg.127 ± 35 leaf pairs/m^2 in the Sikka site and 97 ± 18 leaf pairs/m^2 in the Arambhada lake site). These sites preserve a good and healthy cover of seagrass meadows and can be served as donor sites for seagrass restoration activities in the Gulf. The present study revealed that careful selection of less current influenced, shaded sites may yield a successful restoration of seagrass even in the current and heavy sedimentation influenced marginal reefs like the Gulf of Kachchh.

Table 1 Water quality data recorded at studied sites during 2017

Stations	Season	Post monsoon			Summer			Pre-Monsoon			Monsoon				
	Month	January	February	March	April	May	June	July	August	September	October	November	December	Mean	SD
Pirotan	Temp	20.1	23.9	25.1	28.9	30.0	33.4	34.1	33.6	33.2	26.3	23.6	22.7	27.9	5.0
	pH	7.0	8.5	8.6	7.3	6.1	7.4	7.0	7.8	8.6	8.5	9.0	8.6	7.9	0.9
	Sal	37.2	40.0	39.8	39.7	39.5	39.6	38.6	35.5	37.5	39.4	39.9	39.7	38.9	1.4
	Turbidity	39.2	39.1	35.4	35.1	45.4	44.5	49.7	82.3	59.3	48.3	37.1	39.4	46.2	13.4
	DO	10.9	11.2	15.9	7.8	7.1	7.6	6.2	7.6	6.2	8.2	13.0	8.3	9.2	3.0
Narara	Temp	18.6	22.1	25.7	26.8	31.7	33.9	33.8	33.1	33.3	28.0	24.7	21.9	27.8	5.3
	pH	8.4	8.7	7.2	7.9	7.0	7.3	7.7	7.7	8.5	8.5	8.4	8.8	8.0	0.6
	Sal	39.8	39.8	40.9	40.2	40.2	36.7	37.1	37.0	39.1	39.9	39.7	40.3	39.2	1.4
	Turbidity	38.4	44.3	34.3	54.4	57.6	57.8	58.8	59.6	54.6	47.2	47.6	45.7	50.0	8.4
	DO	17.9	15.1	9.8	9.6	8.5	8.2	7.5	7.2	9.8	10.3	13.6	10.7	10.7	3.2
Mithapur	Temp	24.9	21.4	24.7	28.3	31.6	33.3	26.8	28.6	30.7	31.9	22.9	22.6	27.3	4.0
	pH	7.2	8.4	7.0	7.4	6.9	7.2	6.4	7.5	7.7	8.4	6.5	8.3	7.4	0.7
	Sal	37.4	37.6	22.9	39.6	39.4	40.2	38.3	37.2	37.9	38.0	32.8	39.4	36.7	4.8
	Turbidity	62.8	26.5	31.6	30.4	31.6	34.3	36.5	35.1	64.5	24.9	39.5	34.2	37.7	12.8
	DO	10.2	7.9	6.7	10.7	10.2	8.1	7.3	7.3	6.1	9.1	9.2	9.2	8.5	1.5

Table 2 Pearson correlation matrix of the recorded water quality parameters data

Parameters	Temp	pH	SpCond	Sal	Turbidity	DO	*Halophila ovalis*	*Holodule uninervis*	*Thalassia hemprichii*
Temp	1								
pH	-0.45	1							
SpCond	0.47	-0.35	1						
Sal	0.02	0.11	-0.16	1					
Turbidity	0.60	-0.16	0.36	-0.06	1				
DO	-0.89	0.25	-0.17	-0.12	-0.58	1			
Halophila ovalis	-0.91	0.31	-0.38	0.03	-0.70	0.90	1		
Holodule uninervis	-0.93	0.63	-0.45	0.06	-0.56	0.85	0.88	1	
Thalassia hemprichii	-0.89	0.51	-0.45	-0.03	-0.50	0.85	0.91	0.96	1

Table 3 Stability rate of the transplanted seagrasses at Mithapur nursery during the study

	Stability rate of seagrass during the study (No. of leaves / sq.m)			
	Month-1	Month-2	Month-3	Month-4
Halophila ovalis	78.66	73.15	70.52	69.7
Holodule uninervis	64.64	58.73	51.46	49.05

Acknowledgements The authors thank SPMU (ICZM), Gujarat and Forest Department for extending the facilities and support to survey the MNP area. The first author would like to thank **Rufford Small Grant** for the funding support to develop the nursery technology. Authors would also like to thank Dr. Karthick Raji from NCSCM for his valuable support during this work.

References

Adhavan D, Kamboj RD, Marimuthu N, Bhallodi MM (2014) Seasonal variation and climate change influences coral bleaching in Pirotan island, Gulf of Kachchh Marine National Park. Gujarat Curr Sci 107(11):1780–1781

Bjork M, Short F, Mcleod E, Beer S (2008) Managing seagrasses for resilience to climate change. IUCN, Gland, pp 1–60

Chatterjee A, Ray JS (2017) Source and decomposition pathways of mid-Holocene sediments in the Great Rann of Kachchh, India: Implication for a fluvial scenario during the Harappan Culture. Quat Int 433:177–187

Cunha AH, Marba NN, van Katwijk MM, Pickerell C, Henriques M, Bernard G, Ferreira MA, Garcia S, Garmendia JM, Manent P (2012) Changing paradigms in seagrass restoration. Restore Ecol 20:427–430

Dixit AM, Kumar P, Kumar L, Pathak KD, Patel MI (2010) Economic valuation of coral reef systems in the Gulf of Kachchh, Final Report, World Bank aided Integrated Coastal Zone Management (ICZM) Project, Submitted to Gujarat Ecology Commission, pp 158

Edward JKP, Raj KD, Mathews G, Kumar PD, Arasamuthu A, Bilgi D'Souza N, D S, (2019) Seagrass restoration in Gulf of Mannar, Tamil Nadu, Southeast India: a viable management tool. Environ Monit Assess 191:430. https://doi.org/10.1007/s10661-019-7546-5

English S, Wilkinson C, Baker V (1997) Survey manual for Tropical Marine Resources. Australian Institute of MarineScience, Townsville, Australia, p 390

Fonseca MS (1992) Restoring seagrass systems in the United States. In: Thayer GW (ed) Restoring the nation's marine environment. Maryland Sea Grant College Publ. UM-SG-TS, College Park, pp 92–106

Fonseca MS, Kenworthy WJ, Thayer GW (1987) Transplanting of the seagrasses *Halodule wrightii*, *Syringodium filiforme*, and *Thalassia testudinum* for sediment stabilization and habitat development in the southeast region of the United States, US, Army Corps of Engineers, Washington, D.C. Technical Report EL-87–8. pp 58

Fonseca MS, Kenworthy WJ, Thayer GW (1998) Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters, NOAA'S COASTAL OCEAN PROGRAM Decision Analysis Series No. 12, pp 230

Fonseca MS (1994) A guide to transplanting seagrasses in the Gulf of Mexico. Texas A&M University Sea Grant College Program. TX. TAMU-SG-94–601. pp 26

Gordon DM (1996) Status of seagrass restoration: a review of international literature. In: D. Le Provost, P. Moore (ed) Western Australia

IUCN (2007) Climate change, Coastal Ecosystems. http://iucn.org/places/asia/coastalinfor/docs/Coastal_Ecosystems_Newsletter_6.pdf. Accessed on February 6, October 2007

Johnstone IM (1978) The ecology and distribution of Papua New Guinea seagrasses II, The Fly Islands and Raboin Island. Aquat Bot 5:235–243

Kamboj RD (2014) Biology and status of seagrasses in Gulf of Kachchh Marine National Park and Sanctuary, India. Indian Ocean Newsl 19:8–11

Kenworthy WJ, Fonseca MS (1992) The use of fertilizer to enhance the growth of transplanted seagrasses *Zostera marina* L. and *Halodule wrightii* Aschers. J Exp Mar Biol Ecol 163:141–161

Lanyon JM, Limpus CJ, Marsh H (1989) Dugongs and turtles: grazers in the seagrass system. In: Larkum AWD, Mc Comb AJ, Shepherd SA (eds) Biology of Seagrasses. A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region. Elsevier, Amsterdam, pp 610–634

Matheson FM, Reed J, Dos Santos VM, Mackay G, Cummings VJ (2016) Seagrass rehabilitation: successful transplants and evaluation of methods at different spatial scales. N Z J Mar Fresh Res 51(1):96–109

McMillan C (1984) The distribution of tropical seagrasses with relation to their tolerance of high temperatures. Aquat Bot 19:369–379

Michael LD, Rao G, Krishna KS, Vora KH (2009) Late Quaternary seismic sequence stratigraphy of the Gulf of Kachchh, northwest of India. J Coast Res 25(2):459–468

Nair VR (2002) Status of Flora and Fauna of Gulf of Kachchh, National Institute of Oceanography, Goa. pp 157

Nayruti SB, Nandini RC, Dharmendra GS, Nikhil DD (2011) Sedimentation pattern in Pirotan reef, Gulf of Kachchh, India. J Mar Biol Ass Ind 53(1):1–7

Nobi EP, Dilipan E, Sivakumar K, Thangaradjou T (2011) Distribution and biology of seagrass resources of Lakshadweep group of islands, India. Ind J Geo Mar Sci 40(5):624–634

Paling EI, Fonseca M, van Katwijk MM, van Keulen M (2009) Seagrass restoration. In: Perillo GME, Wolanski E, Cahoon DR, Brinson MM (eds) Coastal wetlands: an integrated ecosystem approach. Elsevier, Amsterdam, pp 687–713

Phillips RC (1980) Planting guidelines for seagrasses. Coastal Engineering Technical Aid No. 80–2. U.S. Army Corps of Engineers Coastal Engineering Research Center, Fort Belvoir, Virginia

Ramaswamy V, Nagender NB, Vethamony P, Illangovan D (2007) Source and dispersal of suspended sediment in macro-tidal Gulf of Kachchh. Mar Poll Bull 54:708–719

Rogers CS (1990) Responses of coral reefs and reeforganisms to sedimentation. Mar Ecol Prog Ser 62:185–202

SAC (2010) Coral Reef Atlas of the World Vol.1 Central Indian Ocean. Space Application Centre, (I.S.R.O.), Ahmedabad, India

Satyanarayana Ch, Ramakrishna (2009) Handbook on hard corals of Gulf of Kachchh, Zool Surv India, Kolkata, India, pp 114

Seddon S (2004) Going with the flow: facilitating seagrass restoration. Ecol Manag Rest 5:167–176

Singh HS (2003) Marine Protected Areas in India. Ind J Mar Sci 32(3):226–233

Singh HS, Pandey CN, Yennawar P, Asari RJ, Patel BH, Tatu K, Raval BR (2004) The Marine National Park and Sanctuary in the Gulf of Kachchh – a comprehensive study on biodiversity and management issues. GEER Foundation, Gandhinagar, p 46

Thangaradjou T, Bhatt JR (2018) Status of seagrass ecosystems in India. Ocean Coast Mngt 159:7–15

WII (2019) Recovery of Dugongs and their habitats in India - an integrated participatory approach. Annual Progress Report-III, pp 184