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Studies on survival and growth rate of transplanted Acroporidae in Gulf of Kachchh Marine National Park, India

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Abstract Fragments of live colonies of scleractinian coral *Acropora* sp. and *Montipora* sp. under the family Acroporiidae were collected from Gulf of Mannar and transplanted in Pirotan, Narara and Mithapur reefs of Gulf of Kachchh Marine National Park. All the transplanted corals survived one complete season and it was observed that 87 nubbins out of the total 110 samples survived in Narara reef and 70 nubbins out of 102 samples stayed alive in Pirotan Island. Growth rate was measured for four months period, and it was found maximum in Narara reef, while minimum in Pirotan Island. The rate of sedimentation was higher during monsoon and low in winter season. Present study showed that species of *Acropora* and *Montipora* are suitable for transplantation in Gulf of Kachchh Marine National Park, Gujarat, India.

Key Words Transplantation · *Acropora* · *Montipora* · Marine National Park · Gulf of Kachchh · India

Introduction

Reef building scleractinian coral family Acroporidae have four genera (*Montipora, Acropora, Astreopora* and *Anacropora*) and about 370 species are reported throughout the world. Probably, species of *Acropora* is totally wiped off in the shallow reefs of Gulf of Kachchh due to over exploitation of corals as a raw material by a cement factory in the vicinity. At present, degraded nubbins in the form of rubbles are found throughout the Gulf of Kachchh islands. Acroporiidae has wider range of growth forms such as branching, digitate, tabular, encrusting and sub-massive forms. Different types of growth forms play a major role in the marine environment and support reef formations. World wide, coral reefs are undergoing drastic decline due to increased sea surface temperature, urbanization of coastal areas, pollution, sedimentation, freshwater runoff, tourism, over fishing, coastal development and overexploitation of coastal resources (Venkataraman and Rajan 1998; Venkataraman et al. 2003; Venkataraman and Wafar 2005; Tamelander and Rajasuriya 2008; Marimuthu et al. 2011, 2013; Geetha and Kumar 2012; Kumar and Geetha 2012a, b, Kumar and Raghunathan 2012; Kumar et al. 2014a, b).

Gulf of Kachchh Marine National Park (GOKMNP) located in the northern most reef region in west coast of India, is the first Marine National Park declared by Government of India in the year 1982 comprising 42 islands. These islands are spread over an area of 620 km^2 and have less diversity of corals when compared to other reefs in India. So far, 49 species of corals belonging to 10 families have been reported in this region (Patel 1978, 1985; Pillai et al. 1979; Pillai and Patel 1988; Rashid 1985; Deshmukhe et al. 2000; Venkataraman et al. 2003; Raghunathan et al. 2004; Satyanarayana and Ramakrishna 2009; Dixit et al. 2010; Ramamoorthy et al. 2012; Parasharya and Padate 2013). These include two species of *Acropora* and seven species of *Montipora* reported only as dead specimens found on the shores. Hence, it was decided to translocate live *Acropora* and

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Montipora nubbins from coral reefs of Gulf of Mannar and transplant them (South East coast of Tamil Nadu, India) to the shallow reefs of Gulf of Kachchh Marine National Park, Gujarat, India.

Reef restoration is important to maintain sustainable management of coral resources in the damaged and degraded reef ecosystems. There are several methods available for reef restoration. Reef restoration is defined as a

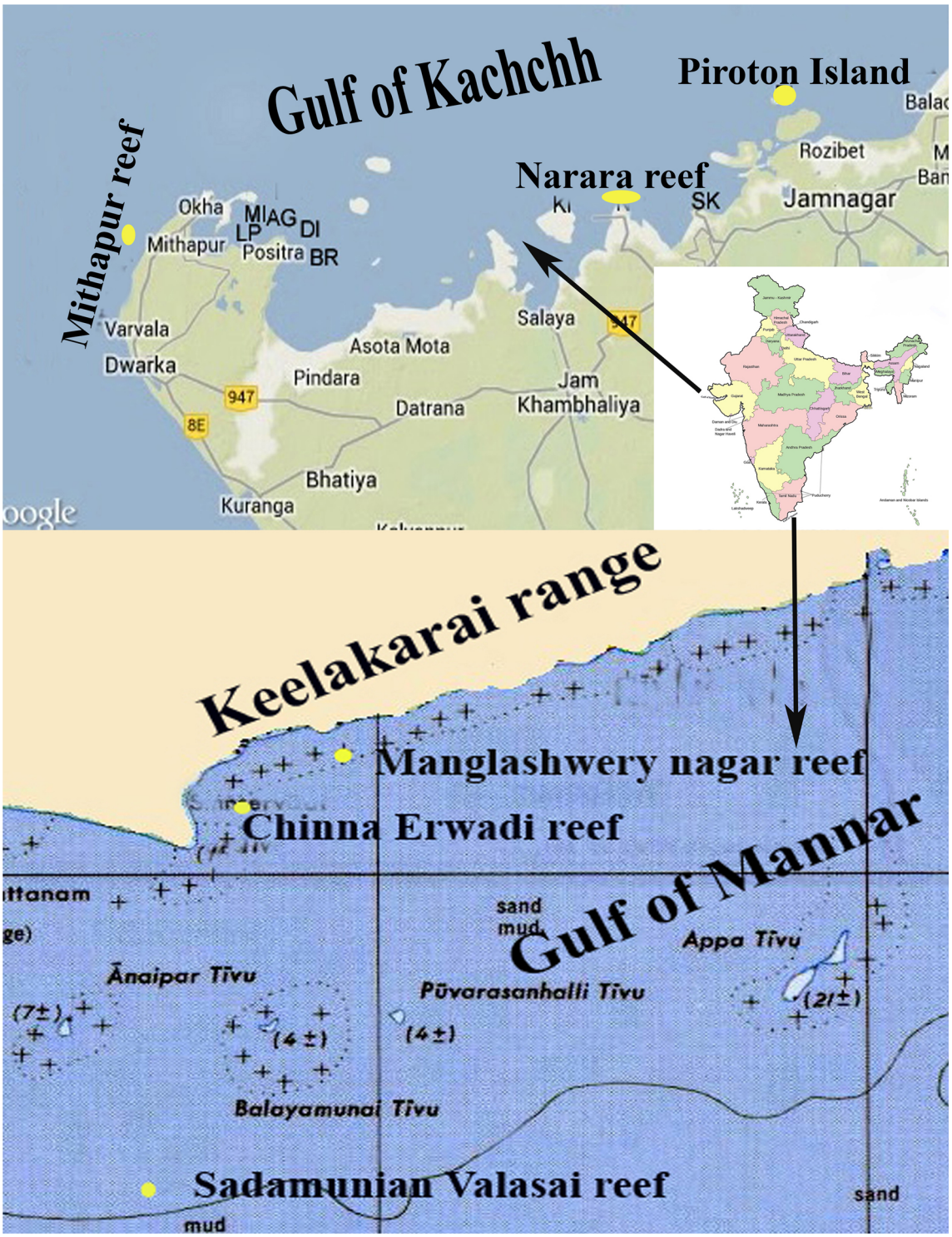

Fig. 1 Study sites in Marine National Park Gulf of Kachchh and Donor sites in Gulf of Mannar

goal of achieving the past glory of an ecosystem, to its original condition (Maragos 1974; Edwards and Clark 1998; Edwards and Gomez 2007). The main objective of the present study is to transplant the corals from a healthy reef to the degraded Gulf of Kachchh Marine National Park reefs especially to Narara, Pirotan and Mithapur area and to monitor and investigate the survival and growth rate of transplanted nubbins of *Acropora* and *Montipora* species.

Material and methods

Coral transplantation was carried out during December 2013 to January 2015 in three different reefs in Pirotan Island (Lat. 22°36.146 N; Long. 69°57.447 E), Narara reef (Lat. 22°28.810 N; Long. 69°44.721 E) and Mithapur reef (Lat. 22°24.127 N; Long. 69°12.496 E) in Gulf of Kachchh Marine National Park. The study area is characterized by fringing reefs (Pirotan Island and Narara reef) as well as sandy bottom (Mithapur).

The nubbins were collected from outside the territory of Gulf of Mannar Marine National Park area; Sadamunian Valasai reef (Lat. 09°05′50.6 N; Long. 78°47′32.4 E), Chinna Erwadi reef (Lat. 09°11′07.3 N; Long. 78°84′ 33.1 E) and Manglashwery nagar reef (Lat. 09°12′ 66.9 N; Long. 78°44′49.3 E) in Keelakarai range (Fig. 1). The donor sites were selected based on the status report of Kumar et al. (2010). Coral nubbins of *Acropora* sp., and *Montipora* sp. were collected using hammer, chisel and cutter (Clark and Edwards 1995). The collected

Fig. 2 Nubbin transportation method for this experimental study. **a** Collected nubbins, **b** Transport from Donor site to Packing lab, **c** Acclimitaise in aquarium tank, **d** Packing in floating condition, **e** 2:3 Ratio seawater and Oxygen, **e** Packed samples ready to Gulf of Kachchh

Fig. 3 Coral nursery and restoration platforms, **a** Cement triangle, **b** Cement platform, **c** & **d** Iron tables, **e** Coral tree nursery, **f** Rope nursery

nubbin samples were kept in an aquarium tank for 2 to 3 h to acclimitaise as well as to remove the mucous with the help of protein skimmer. Then, the processed samples were packed in floating condition with the help of polythene packets with seawater and oxygen in 2:3 ratio (Fig. 2). Within 24 h, the samples nubbins were trasported by air from the donor site (Gulf of Mannar) to the recipient site (Gulf of Kachchh). The transported nubbins were then placed in coral tree nurseries and rope nurseries for two months in order to check the survival (Fig. 3). The healthy nubbins were safely tied to cement blocks with copper wire and transplanted in suitable sites (Zobrist 1999; Thornton 1999; Graham and Fitzgerald 1999).

Table 1 Number of transplanted branching scleractinian corals survival rate during the study period (Dec. 2013 to Jan. 2015) in Gulf of Kachchh

	Pirotan				Narara				Mithapur			
	Total coral transplanted	Alive	Detached	Dead	Total coral transplanted	Alive	Detached	Dead	Total coral transplanted	Alive	Detached	Dead
Acropora	52	34	6	12	40	35	2	3	30	26	1	3
Montipora	50	36	5	9	70	52	6	12	70	46	10	14
Total	102	70	11	21	110	87	8	15	100	72	11	17

In the present study, three types of platforms were chosen as a substrate for transplantation process. i) Concrete triangle for a high turbid environment at a depth of 2.0 m in Pirotan Island. ii) Flat cement platform for intertidal reef flat at less than 1.0 m depth in Narara reef and iii) Iron table platform for sandy bottom at 5.0 m depth in Mithapur reef (Fig. 3). Each technique has an advantage which depends on species specific and environmental variables.

The linear growth was assessed (English et al. 1997) for four months period between September, 2014 and January, 2015. The results were analysed using multivariate analyses using PAST version 2.15 (Hammer 2012).

Results

Three hundred and twelve branching coral nubbins (*Acropora* sp. and *Montipora* sp.) were transplanted from Gulf of Mannar to Gulf of Kachchh (Pirotan Island, Narara reef and Mithapur reef). The survival rate of transplanted branching coral nubbins are summarized in Table 1. The preliminary results indicated successful rate of survival of transplanted nubbins. It is found that the transplanted coral nubbins had overcome the sedimentation load in the water, temperature variation, algal competition as well as the strong tidal currents that prevailed in the area.

In this study, maximum survival was noticed in Narara reef followed by Mithapur and Pirotan Islands. The mortality rate was high in Pirotan Island followed by Mithapur and Narara reef (Table 2).

The linear growth extension of transplanted coral nubbins were measured as change in length (cm) for individually tagged branches during the study period. The linear extensions observed in this study were found to be consistent between sites for all five species which are presented in Table 3, Figs. 4 and 8. However, there are significant differences in growth rate of the trasplanted corals.

Ecological variation of the study sites are presented in the Table 4. A maximum of 30.6 °C sea surface temperature was noted in Mithapur reef during summer season and minimum of 23.8 °C in Pirotan Island during winter season. The variation in pH of the seawater in the study area was not pronounced, maximum was reported at Pirotan Island (8.2) and minimum at Mithapur and Narara (7.7). The range of salinity was between 37.5 ppt to 40.2 ppt. The maximum turbidity was reported in Narara reef (65.4 NTU) and minimum in Mithapur reef (23.2 NTU).

The sedimentation rate ranged between 14.7 mg/cm^2/ day to 94.3 mg/cm^2/ day, 18.3 mg/cm^2/ day to 74.9 mg/cm^2/ day and 8.8 mg/cm^2/ day to 74.6 mg/cm^2/ day in Pirotan, Narara

Table 2 Status of survivorship and mortality for each transplant species in transplanted sites in Gulf of Kachchh

Species	Pirotan (2 m depth)				Narara (1 m depth)				Mithapur (3 m depth)			
	Survivorship (%)	Detached (%)	Mortality (%)	Total number of colonies (N)	Survivorship (%)	Detached (%)	Mortality (%)	Total number of colonies (N)	Survivorship (%)	Detached (%)	Mortality (%)	Total number of colonies (N)
A.muricata	50	12.5	37.5	16	93.3	0	6.7	15	87.5	0	12.5	8
A. nobilis	72.2	5.56	22.2	18	83.3	8.3	8.3	12	84.6	7.7	7.7	13
A.cytherea	87.5	0	12.5	8	100	0	0	8	100	0	0	4
A.diversa	60	30	10	10	60	20	20	5	80	0	20	5
M.digitata	72	10	18	50	74.3	8.6	17.1	70	65.7	14.3	20	70
Total				102				110				100

Table 3 Linear extension growth rate of branching scleractinian corals during study period (Sep, 2014 to Jan., 2015), growth rates are given as cm ± SD

Transplanted site	*A. muricata* (cm)	*A. nobilis* (cm)	*A. cytherea* (cm)	*A. diversa* (cm)	*M. digitata* (cm)
Pirotan	1.00 ± 0.40	1.29 ± 0.35	0.78 ± 0.23	0.60 ± 0.18	2.06 ± 0.57
Narara	1.32 ± 0.36	0.61 ± 0.17	1.00 ± 0.34	1.32 ± 0.39	2.14 ± 0.59
Mithapur	0.74 ± 0.22	1.28 ± 0.35	1.43 ± 0.36	0.64 ± 0.19	2.09 ± 0.67

and Mithapur, respectively. The highest value (94.3 mg/cm^2/ day) of sedimentation occurred during September in Pirotan Island and lowest (8.8 mg/cm^2/ day) in Mithapur reef during January 2014 (Table 4).

De-trended correspondence analysis showed that the survival rate of transplants were found in the order of *A. diversa* followed by *M. digitata*, *A. nobilis*, *A. formosa* and *A. cytherea,* in the Pirotan Island. Moreover, the survival rate of all transplanted samples were found to be higher in Pirotan Island followed by Narara and Mithapur reefs (Figs. 5, 6, 7 and 8).

The mortality rate of transplanted nubbins were observed to be very minimal. The maximum mortality rate of 21 samples were observed in Pirotan Island and minimum of 11 samples in Mithapur reef. The mortality of *M. digitata* and *A. diversa* was found in the Narara and Mithapur reefs whereas that of *A. formosa* was observed in Pirotan Island.

Notable growth rate was observed in all the samples which were found to be in the range between 0.60 and 2.14 cm in Pirotan and Narara reefs during the study period. The growth rate of *A. nobilis* was found to be higher followed by *M. digitata* in Pirotan Island. The growth rate of *A. cytheria* was found to be maximium in Mithapur reef whereas, it was *A. diversa* in the Narara reef. Based on the growth rate observed in all the transplanted nubbins, more than 90 % similarity was observed between Pirotan Island and Mithapur reef. In addition, 82 % similarity in the growth rate of all transplanted nubbins observed between all the study sites.

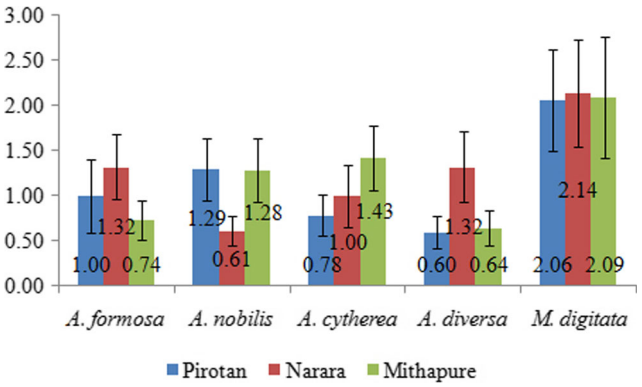

Fig. 4 Linear extension growth rate of branching scleractinian corals, growth rates are given as cm ± SD (*A. muricata* = *A. formosa*)

Discussion

Among 478 species of corals known from the seas around the Indian reef ecosystem, 424 species belonging to 86 genera and 19 families are reported from Andaman and Nicobar Islands (Venkataraman et al. 2012), 104 species belonging to 37 genera and 13 families from Lakshadweep Islands and 117 species belonging to 40 genera and 14 families from Gulf of Mannar Islands (Raghuraman et al. 2014).

In Gulf of Kachchh, Satyanarayana and Ramakrishna (2009) reported 54 species belonging to 27 genera and 10

Table 4 Season wise ecological parameters at three study sites

S. No	Parameters	Winter (10th Jan.-14)			Summer (5th May-14)			Monsoon (12th Sep. – 14)		
		P	N	M	P	N	M	P	N	M
1.	Temp {°C}	23.8	24.9	24.2	28.2	29.3	30.6	25.9	27.8	26.9
2.	pH	7.8	7.7	7.7	8.2	7.9	7.8	7.8	7.8	7.8
3.	Salinity [ppt]	39.9	39.7	37.5	39.8	38	38.1	39.6	40.2	38.2
4.	Turbidity [NTU]	25.4	34.3	23.2	41.1	47.3	31.6	33.5	65.4	36.1
5.	Sedimentation rate (mg/cm^2/day)	14.7	18.3	8.8	62.1	68.8	64.2	94.3	74.96	74.6

P Pirotan Island, *N* Narara reef, *M* Mithapur reef

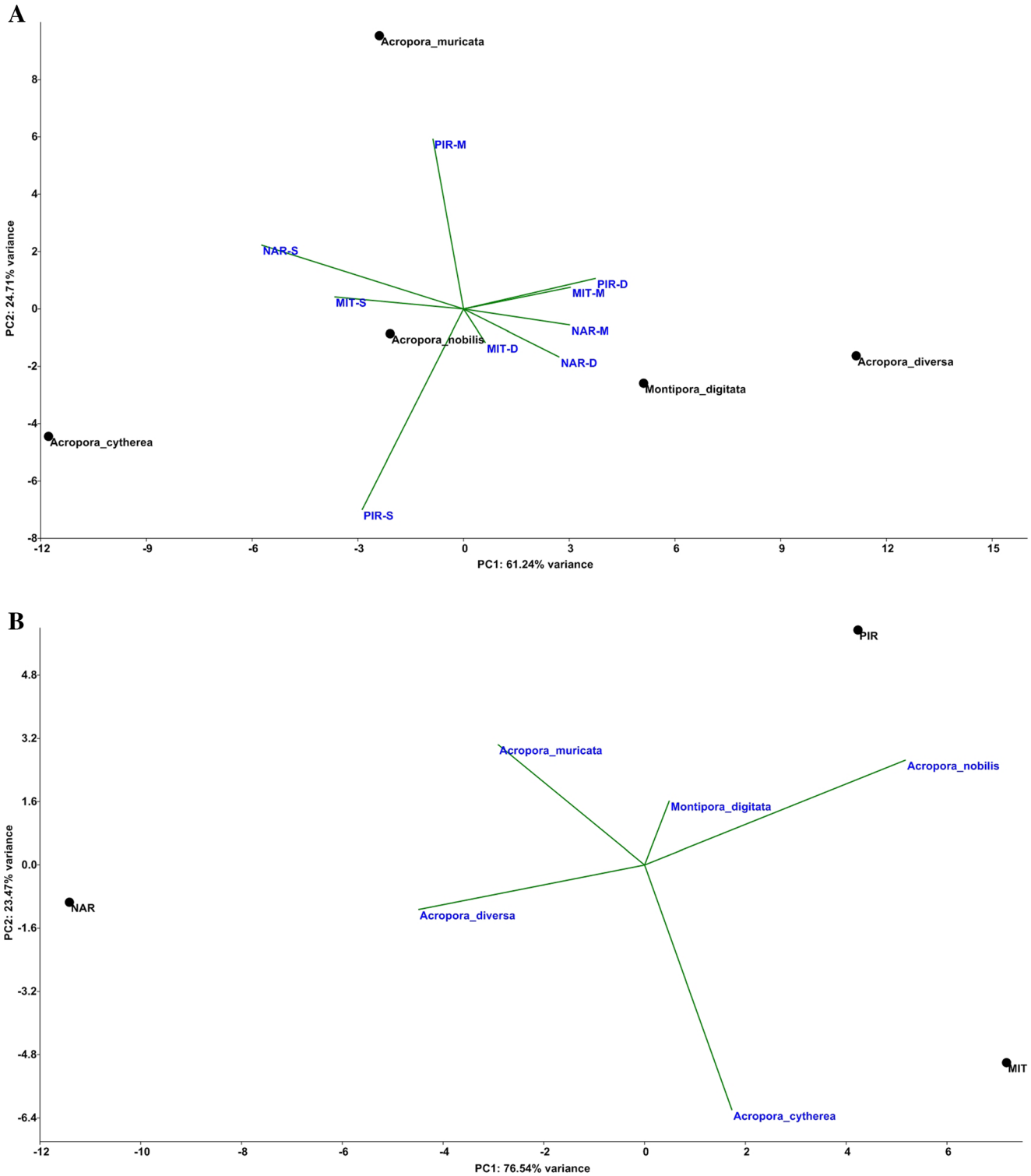

Fig. 5 **a** Principal Component Analyses (PCA) of survivorship and **b** growth rate variance in the MNP, GoK (*A. muricata* = *A. formosa*)

families of which, *Acropora* sp. and *Montipora* sp. were reported based on dead fossil samples found on the shores. These species were reported as extinct in Gulf of Kachchh probably due to the high temperature fluctuation as well as high sedimentation rate (Pillai et al. 1979).

Edwards et al. 2006, stated that coral transplantation is a tool for securing the restoration and conservation of endangered coral species. The present study was undertaken with an objective to restore *Acropora* sp. and *Montipora* sp. in Gulf of Kachchh reefs. As already

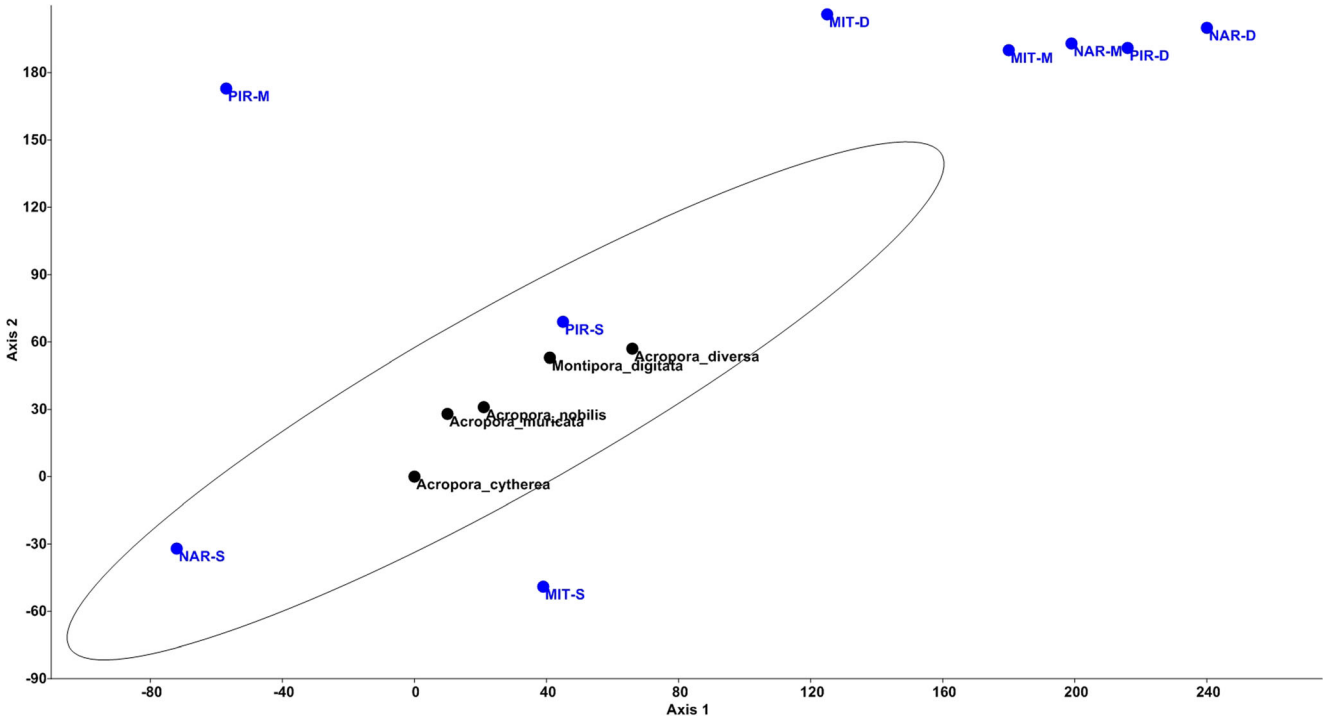

Fig. 6 Correspondence analysis of transplanted coral sample survivorship between three study stations (*A. muricata* = *A. formosa*)

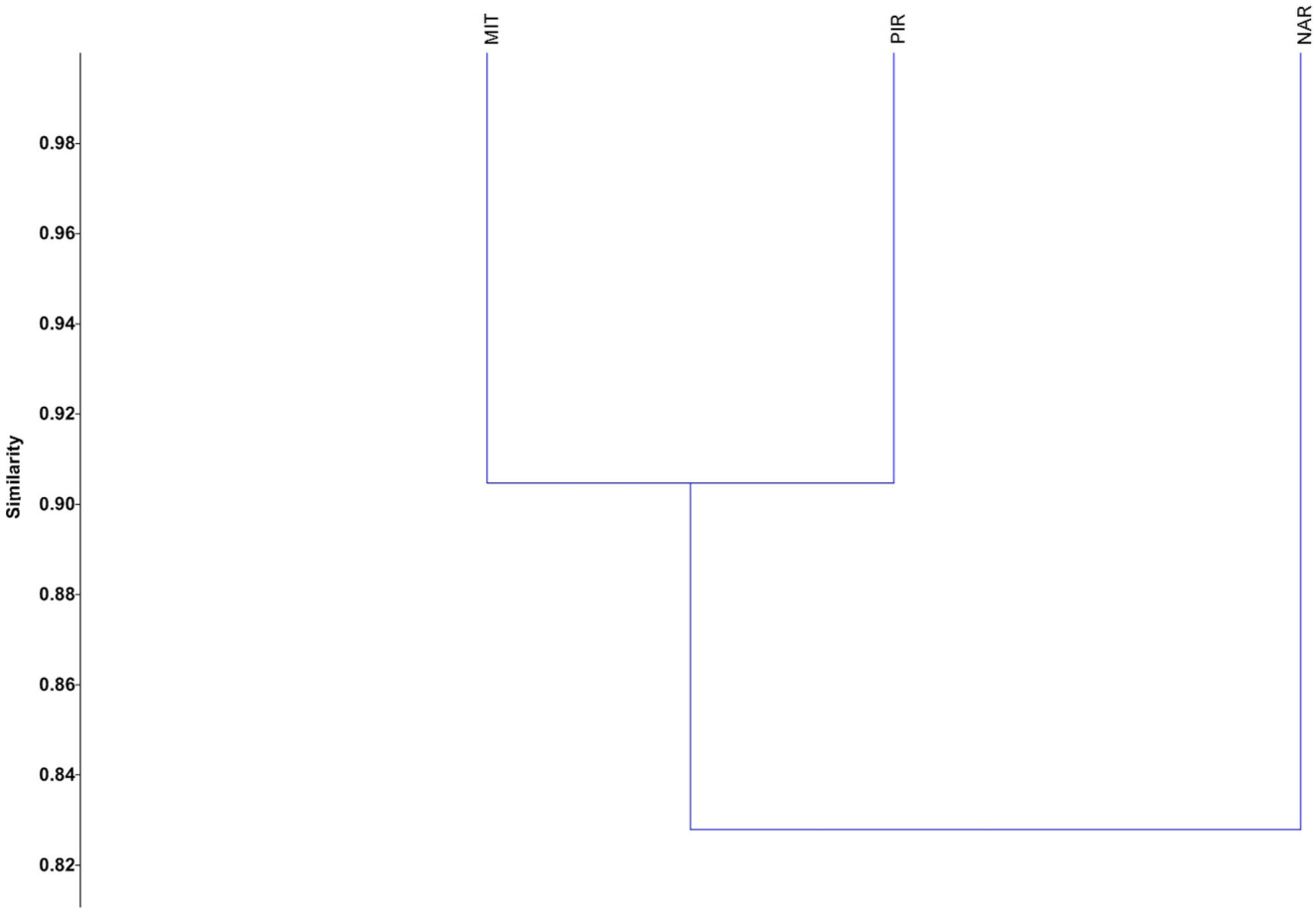

Fig. 7 Bray-Curtis cluster analysis under paired linkage based on similarity growth rate in the MNP, GOK

Fig. 8 Linear extension growth rate of branching scleractinian corals in Marine National Park Gulf of Kachchh, **a** *Acropora cytherea,* **b** & **c** – *A. nobilis,* **d** *A. formosa*, **e** *A. diversa*, **f** *M. digitata*

mentioned, the samples were obtained from the donor sites in Gulf of Mannar (south east coast), to the recipient sites in Gulf of Kachchh (north west coast). The approximate distance from the donor site to the recipient site is 2600 km. In India, transplantation and other reef restoration experiments are very few confined to local species. Mathews and Edward (2005) reported branching and massive coral restoration by using local species in the Gulf of Mannar. By using local species, preliminary examinations on the factors which are influencing the transplanted coral nubbins were also studied in Lakshadweep (Venkatesh and Koya 2006). However, the present study ventured into an altogether new horizon in India, that of estimating the survival and the growth rate of transplanted coral nubbins translocated from a far-away coral reef.

Previous studies have reported that the major limitimg factor of the survival of transplanted corals are the sea

Table 5 Regional-wise growth rate comparison of transplanted coral nubbins

S. No.	Transplanted coral species	Growth rate per month	Study sites	References
1	*Acropora* sp.	0.67 cm	Davies Reef, Australia	Oliver et al. (1983)
2	*A.cytherea*	0.48 cm	Maldive Isalnds	Clark and Edwards (1995)
	A.hyacinthus	0.36 cm		
	A.divaricata	0.35 cm		
	A.humilis	0.16 cm		
3	*Acropora cytherea*	0.46 mm	Solitary Islands	Harriott (1999)
4	*Acropora valida*	0.80 mm	Solitary Islands	Harriott (1999)
5	*A.grandis*	0.28 cm	Phi Phi Island, Thailand	Putchim et al. (2008)
	A.muricata	0.38 cm		
6	*Acropora* sp.	0.34–0.42 cm	Lord Howe Island	Anderson et al. (2012)
7	*Acropora muricata*	0.33 cm	Narara reef	Present study at Gulf of Kachchh
	Acropora nobilis	0.32 cm	Pirotan Island	
	Acropora cytherea	0.36 cm	Mithapur	
	Acropora diversa	0.33 cm	Narara reef	
	Montipora digitata	0.54 cm	Narara reef	

surface temperature (Kleypas et al. 1999) and the colonisation of turf algae and other algal growth over the corals (Kamalakannan et al. 2014; Joshi and Marimuthu 2015). However, in the present study the transplanted colonies have endured the suffocation caused by the turf algae as reported by Wilson and Marimuthu (2012).

The fastest growing scleractinian corals during reef restoration processes are reported as *Acropora* sp., *Montipora* sp. and *Pocillopora* sp. in the tropical countries (Buddemeier and Kinzie 1976).

In the present study, the linear extension of four species *Acropora* and one species of *Montipora* were studied (Table 3). Growth rate from different regions world vide (Oliver et al. 1983; Harriott 1999; Putchim et al. 2008; Anderson et al. 2012) have been presented along with the growth rate of corals observed in the present study (Table 5).

Physicochemical parameters are vital for the normal growth of corals. Hence a detailed investigation of the effect of sea surface temperature pH, Salinity, Turbidity and rate of sedimentation on the growth of the transplanted corals were studied at the three sites (Table 4). Seasonal changes of hydrographic and sedimentation rate were studied in detail at the donor site (Gulf of Mannar) by Kumar and Geetha 2012a, b and Kumar et al. 2014a, b. It is noted that the sedimentation season was similar in both sites; however the rate of sedimentation was dissimilar, in the present study.

A successful coral transplantation depends on the site, coral species, the sample size, environmental condition and also the frequency of monitoring. The present study proved to be a success in the coral restoration initiative and hence it is recommended that Acroporiidae species are suitable for large scale transplantations in future at Marine National Park, Gulf of Kachchh.

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