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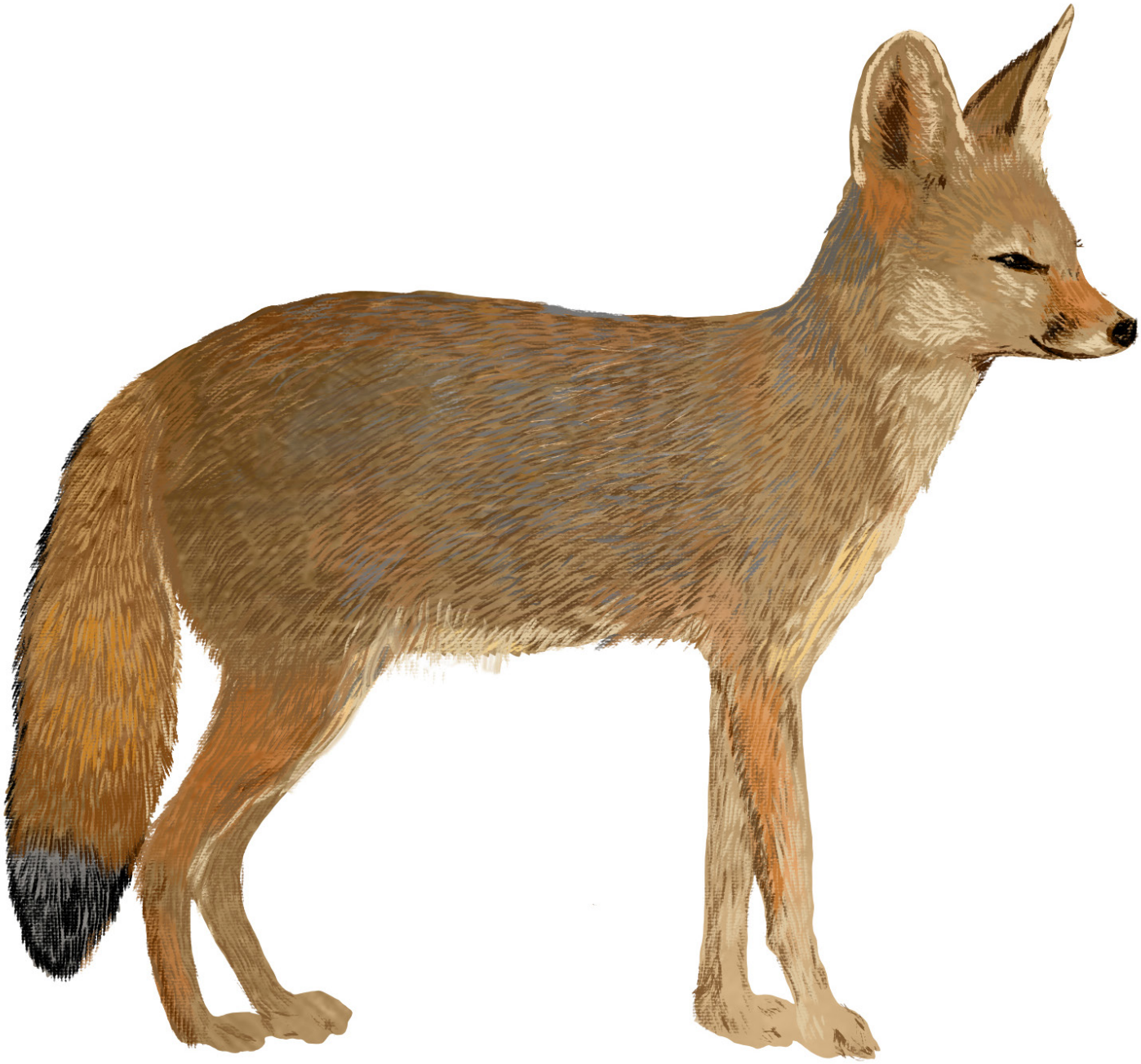

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ARTICLE

Successful establishment of a coral nursery for active reef restoration in Kavaratti Island, Lakshadweep archipelago

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Abstract: The achievements in successfully establishing coral nurseries using asexually reproduced transplants in Kavaratti Island, Lakshadweep archipelago are presented. During the present study, the survival and growth of 180 fragments of corals fixed on concrete blocks with iron frames laid over a 40 m^2 area near reefs inside the lagoon of Kavaratti atoll were assessed. Significant differences in growth were observed between acroporid and non-acroporid corals after two years of transplantation. *Acropora muricata* (31.1 ± 0.4 cm) and *Isopora palifera* (15.9 ± 3.4 cm) displayed the highest and lowest growth rates among acroporid corals and *Pocillopora damicornis* (481.9 ± 68.4 cm^3) and *Hydnophora microconos* (33.4 ± 15.7 cm^3) had the highest and lowest rates, among non-acroporid corals. A diverse fish assemblage comprising 21 species belonging to 10 families was observed at the transplantation site, with *Chromis viridis* and *Dascyllus aruanus* being the dominant species. The success achieved in this study makes it an ideal approach to be used elsewhere in the Lakshadweep archipelago and the wider Indian Ocean region to develop underwater tourism and promote science-based management and restoration of coral reefs.

Keywords: Acropora, Arabian Sea, artificial substrate, atoll, coral fragments, coral nursery, coral reef, Indian Ocean, lagoon, transplantation.

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Author contributions: SS and KKI – conceptualisation, design of work and supervision. CAR – Field work, coordination, data collection and manuscript writing. RR, KKI and SS manuscript review, editing and comments.

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INTRODUCTION

Despite being of the most spectacular, productive, and biologically diverse marine ecosystems (Odum & Odum 1955; Connell 1978; Moberg & Folke 1999), coral reefs face unprecedented threats from various natural and anthropogenic stressors (Wilkinson 1998; Obura et al. 2022), including deteriorating water quality, destructive fishing methods, over-exploitation of reef fauna, emerging diseases, and climate change (Hoegh-Guldberg 1999; Bellwood et al. 2004; Halpern et al. 2019; Schartup et al. 2019; Issifu et al. 2021). Almost half of the world's coral reef ecosystems are now degraded (IPBES 2019), many reefs in southern Asia, and the Pacific region continue to decline steadily (Burke et al. 2011), and others like the western Indian Ocean region are predicted to have high risk of collapse within the next 50 years (Obura et al. 2022). Additionally, the catch-per-unit effort of coral reef-associated fishes has been declining by 60% since the 1950s, and the capacity of reefs to provide critical ecosystem service declined by 50% during the same period (Eddy et al. 2021). The prospects for coral reef ecosystems and their resources appear bleak in the coming future.

Around the world, damaged coral reef communities recover very slowly, particularly when there are changes in benthic morphology or chronic degradation in prevailing environmental conditions (Roth et al. 2018). The complete recovery of the reef to pre-existing ecological community structure and ecosystem services may extend to hundreds or even thousands of years without active intervention by resource managers (Hein et al. 2020). Despite its limitations and reservations (Omori 2019; Boström-Einarsson et al. 2020), coral reef restoration efforts are accelerating worldwide to offset the rate of reef health declines (Boström-Einarsson et al. 2020; Suggett & van Oppen 2022). The primary objective of coral restoration is to transplant fast-growing and healthy coral fragments, to rebuild dead reefs to their original state, or as nearly as possible to the original state, and thus increase the live coral coverage (Ramesh et al. 2020). Massive corals are also recommended for transplantation due to their lower susceptibility to damage and mortality, which can ultimately produce the habitat required for fish and other coral morphologies (Ammar et al. 2013). While fast-growing corals are ideal candidates for active reef restoration, they are highly susceptible to bleaching-related impacts and mortality. Therefore, any active restoration should focus on both branching and non-branching corals to achieve fruitful results (Ramesh et al. 2020).

The Lakshadweep archipelago, part of the Laccadive-Maldives-Chagos group of islands, comprise 12 atolls, three reefs, five submerged banks, and ten inhabited islands (Kaladharan & Anasukoya 2020). Lakshadweep reefs are the only atolls among the Indian reefs. The coral reefs of this archipelago have been threatened and destroyed by a range of stressors, including regular bleaching events, cyclonic disturbance, and anthropogenic interventions (Riyas et al. 2020). These threats necessitate the development and implementation of active coral restoration programs. In the Lakshadweep archipelago, transplantation of corals can help create habitats that provide alternative livelihoods for the fishing community and, in particular, serve as an ideal management strategy for aquarium fish collectors without damaging prime coral colonies in the reef. The present study aims to develop an effective transplantation method for establishing a coral nursery in the Kavaratti lagoon of the Lakshadweep archipelago, focusing on the use of fast-growing coral species to facilitate the rapid restoration of degraded reefs. Also, it aims to understand the composition and abundance of reef fish assemblages that colonize near the transplantation site based on the growth and survival of transplanted fragments.

MATERIALS AND METHODS

Study site

Kavaratti Island (10.558°N 72.623°E), part of the Lakshadweep archipelago, is located off the southwestern coast of India (Image 1). The area of Kavaratti lagoon is approximately 3.63 km^2, and most parts of its seabed are covered by coral sand, dead corals, and rubbles, together with well-developed live coral communities near the inner reef slope adjacent to the restoration site. The total cover of the live coral community at Kavaratti Atoll was estimated to be 21.7% (Idreesbabu et al. 2017). The selected location for attempting the restoration experiments is a 2.5-m-deep area within the lagoon of the Kavaratti Atoll, consisting of a sandy bottom (Image 2). The coral fragments were collected from different donor sites or locations of the lagoon including the intertidal zone, inner reef lagoon, and reef crest of the atoll, to obtain different fragments grown in different conditions and locations in the lagoon. The donor sites were approximately 500 m to 2.5 km away from the transplantation site.

Selection of the donor and recipient sites

This restoration effort focused on using indigenous healthy corals found in the shallow lagoons of Kavaratti islands because of their natural resilience to the local environment. The long-term success and resilience of transplanted corals rely heavily on genetic diversity. Accordingly, using donor sites with high genetic diversity is preferable to enable transplanted corals to adjust to changing environmental conditions. Coral species were chosen from the donor site because of their rapid growth and abundance.

The recipient site chosen for the transplantation had environmental conditions with minimal signs of stressors, such as pollution, sedimentation, or overfishing to maximize the survival and growth of the transplanted corals. In the same way, a nearby site that has been damaged by coral fragmentation was also taken into consideration as a potential donor site.

Artificial substrate

Coral nursery units were made of angle bars and iron mesh (2 × 2 × 0.5 m). Concrete blocks (25 x 20 cm) were used as the artificial substrate for coral fixing (Image 3a). To increase the durability of the coral nursery unit and prevent the early onset of rust and corrosion, food-grade epoxy paint was applied and allowed to dry for three days before deployment. A total of 10 iron frames (4 m^2) were arranged at the restoration site.

Coral transplantation

Coral fragments available around the lagoon were used for transplantation, as they were grown in the local environment. Branches of acroporid and non-acroporid corals that naturally grew on artificial substrates, such as concrete structures and buoys in the lagoon, were pruned to obtain coral fragments. Collected coral fragments were transferred underwater using plastic baskets by scuba diving. They were identified up to the species level using an underwater coral finder following Kelley (2009). Selected and sized nubbins were then fixed on rectangular cement blocks using plastic cable ties and these blocks were fixed into the deployed iron

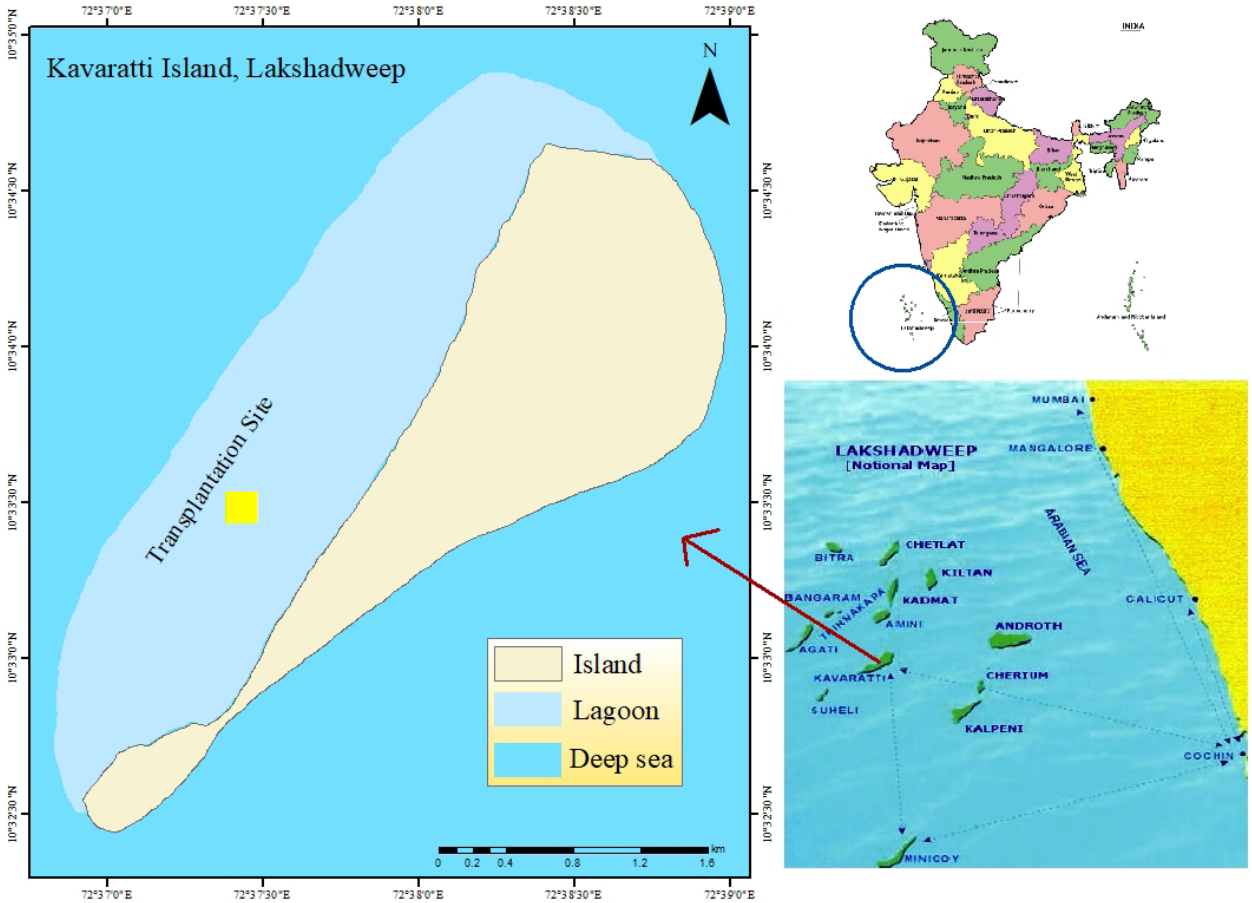

Image 1. Map of the lagoon off Kavaratti Island, Lakshadweep archipelago, India, showing the location (marked in yellow) of the transplantation site.

Image 2. Site selected for coral transplantation in the Kavaratti lagoon, Lakshadweep archipelago (before restoration).

mesh frame. Twenty coral fragments each measuring 7–11 cm in length were fixed in each iron mesh frame. The number of coral fragments, species, and size used at the beginning are provided in Tables 1 and 2. The debris, algae, and sand particles deposited on the transplanted fragments were removed weekly for the first two months and fortnightly thereafter using a soft brush. Survival and growth rates were monitored monthly from January 2016 until January 2018.

Data collection and analysis

The growth rate of the massive corals was reported as colony height (h) in centimeters (cm) and approximate colony volume (V), calculated using a formula $V = r^2h$, of which 'r' was calculated from length (l) and width (w) as (l⍰w) /4 (Yucharoen et al. 2013). The total growth rate of acroporid coral was measured to the nearest centimeter and compared between species. Seawater temperature was recorded using a Hobo data logger (HOBO Pendant UA-002-64) and the turbidity data was obtained from a data buoy deployed in Kavaratti, as part of a joint initiative by the Department of Science and Technology and the National Institute of Oceanography, Goa. The survival rate was calculated based on the percentage of corals that survived the initial fixing. Survival of coral transplants (expressed as the percentage of the live individuals which survived the initial fixed) was recorded monthly. Belt transects (Brock 1954) measuring 10 x 5 m which were placed horizontally to the coral restoration site were used to quantify the density of associated fish species. Fish species were identified primarily using Kuiter (2014) and Allen & Steene (2007). Further, the fishes were identified to species-level taxonomy following Fricke et al. (2023).

RESULTS

Growth rates of transplanted corals monitored for two years revealed higher annual values for acroporid, than non-acroporid corals. Growth rate varied widely between species (Tables 1 & 2), with the highest growth rates observed in *Acropora muricata* (31.1 ± 0.4 cm, n = 25), *A. hyacinthus* (21.7 ± 1.5 cm, n = 14) and, *A. gemmifera* (17.5 ± 2.8 cm, n = 10) (Table 1, Figure 1), and lowest growth rates in *Pocillopora damicornis* (481.9 ± 68.4 cm^3, n = 12), *P. grandis* (273.12 ± 36.1 cm^3, n = 12), and *Echinopora lamellosa* (95.1 ± 21.3 cm^3, n = 8) (Table 2, Figure 2). A comparison of the mean initial lengths of the acroporid fragments showed no significant variation ($F = 2.75$; $P > 0.01$) however the final growth showed a significant variation ($F = 162.91$; $P < 0.01$). This denotes variation in the growth of different species selected for the study even though the initial sizes are uniform. In

Table 1. Size (Mean ± SD) of transplanted acroporid corals in Kavaratti lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

Coral species	Number of fragments (N)	Initial size (cm)	Size after two years (cm)	Growth rate (cm/2years)
Acropora austera	15	7.64 ± 1.2	24.7 ± 0.9	17.08 ± 1.04
Acropora digitifera	15	7.3 ± 0.9	23.9 ± 0.8	16.6 ± 1.3
Acropora gemmifera	10	7.7 ± 2.9	25.2 ± 2.8	17.5 ± 2.8
Acropora hyacinthus	14	9 ± 1.5	30.6 ± 1.6	21.7 ± 1.5
Acropora muricata	25	8.2 ± 2.6	39.3 ± 2.7	31.1 ± 0.45
Acropora tenuis	11	6.53 ± 0.7	22.6 ± 0.5	16.22 ± 0.6
Isopora palifera	10	9.4 ± 2.5	25.3 ± 3	15.9 ± 3.4

Table 2. Volume (Mean ± SD) of transplanted non-acroporid corals in Kavaratti Lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

Coral species	Number of fragments (N)	Initial volume (cm^3)	Volume after 2 years (cm^3)	Growth rate (cm^3/2years)
Echinopora lamellosa	8	18.6 ± 8.9	113.7 ± 50.5	95.1 ± 21.3
Gardineroseris planulata	8	8.8 ± 1.2	42.5 ± 29.3	33.7 ± 11.5
Hydnophora microconos	8	29.5 ± 8.6	62.9 ± 27.7	33.4 ± 15.7
Lobophyllia hemprichii	10	33.6 ± 19.8	68.8 ± 29.1	35.2 ± 9.5
Platygyra daedalea	12	24.1 ± 9.9	61.99 ± 31.2	37.89 ± 14.9
Pocillopora damicornis	12	20.04 ± 11.5	502.008 ± 115.9	481.9 ± 68.4
Pocillopora grandis	12	29.2 ± 13.8	302.321 ± 53.36	273.12 ± 36.1
Porites lobata	10	15.7 ± 11.9	49.2 ± 36.2	33.5 ± 23.5

non-acroporids, the initial nubbins taken significantly varied in volume ($F = 6.06$; $P < 0.01$), and the final growth of the fragments also varied significantly ($F = 372.82$; $P < 0.01$).

During the study period, water temperature (Figure 3) varied between 25.9^{0}C (in August 2018) and 31.6^{0}C (in May 2016), and turbidity (Figure 4) between 0.6 NTU (in February 2018) and 6.3 NTU (in July 2018).

The underwater visual census showed the presence of a diverse fish assemblage at the transplantation site, with around 21 species belonging to 10 families. The major families of fish represented at the transplantation site included Acanthuridae, Balistidae, Chaetodontidae, Holocentridae, Labridae, Monacanthidae, Pomacentridae, Scorpaenidae, Serranidae, and Zanclidae (Table 3). The numbers of *Chromis viridis* and *Dascyllus aruanus* were higher than other species, suggesting that the transplantation site acts as a good spawning ground, as *Pocillopora* sp. and *Acropora* sp. were preferred as a breeding space. The health of the transplanted corals could also be ascertained from the occurrence of coral-feeding fishes of the genus *Chaetodon* and herbivorous fishes such as those belonging to the family Acanthuridae. The results indicated that fish diversity varied based on the nature of the benthic substrate at the transplantation site, the species composition of the corals, as well as the dietary preferences of the fish.

DISCUSSION

Scientific transplantation, the most expensive and effective method for coral rehabilitation, has been extensively applied as a management option in many countries of the world (Rinkevich 2005; Ferse 2010; Garrison & Ward 2012), while research on coral restoration have been carried out in more than 56 countries (Boström-Einarsson et al. 2020). Most projects on coral restoration are conducted in the USA, Philippines, Indonesia and Thailand, with the majority of these involving coral fragmentation, or transplantation of coral fragments (Boström-Einarsson et al. 2020). These restoration programs have successfully accelerated the recovery of degraded coral reefs due to natural and anthropogenic disturbances. However, they are limited to particular environmental conditions such as substrate type, sexual recruits and sheltered zones (Edwards & Gomez 2007; Edwards 2010; Rinkevich 2014). Different

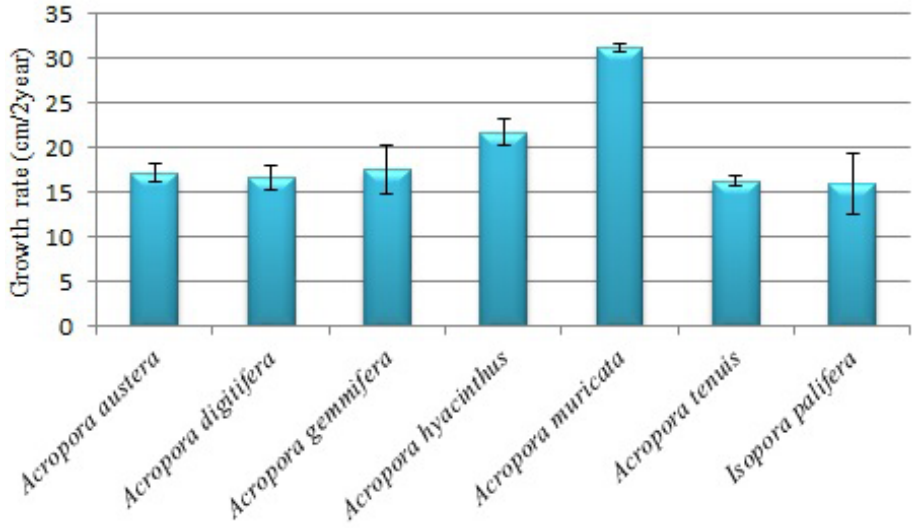

Figure 1. Growth rates observed in transplanted acroporid corals in the Kavaratti lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

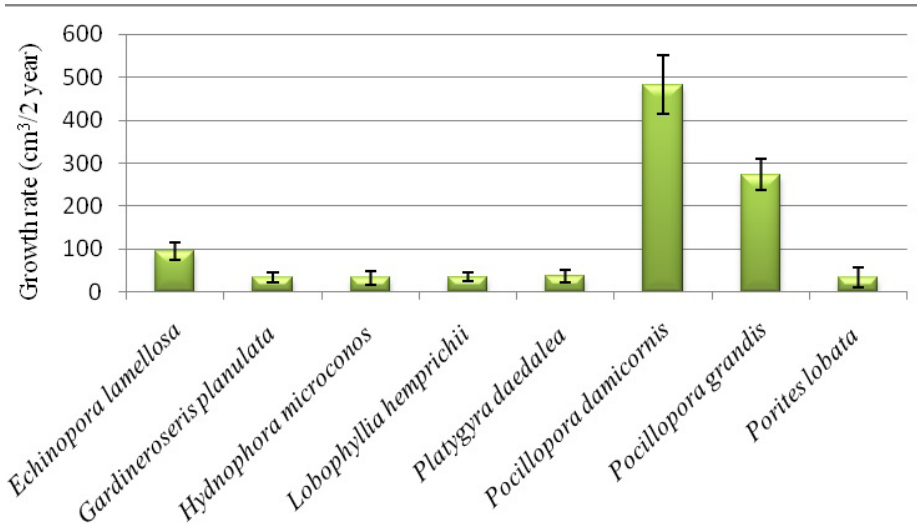

Figure 2. Growth rates observed in transplanted non-acroporid corals in the Kavaratti Lagoon, Lakshadweep archipelago, after two years (January 2016 until January 2018).

countries have developed many alternative techniques over the last few decades, which involve directly fixing coral colonies and fragments onto a reef substrate, which is the most commonly practiced technique (Boström-Einarsson et al. 2020). Although the coral fragment technique used for coral restoration is common worldwide, this study is unique in that it has used such a large number of coral nubbins with long-term monitoring for the first time through the Department of Science and Technology, Lakshadweep Administration.

All transplanted coral species in the present study showed reasonable growth rates, and an ability to self-attach to concrete blocks and augmented polyps within the lagoon. Between the groups, acroporid corals displayed a faster growth rate than non-acroporid corals, suggesting that fast-growing acroporid corals are more favourable for providing quick coral reef ecosystem services. The structural morphology of *Acropora* facilitates the provision of food, shelter, and breeding sites for many organisms in the marine ecosystem, and plays a critical overall role in creating a healthy ecosystem in the sea, as well as in the formations of islands, and for coastal protection (Bruckner 2002). It is for these reasons that most global restoration projects focus on fast-growing, branching, acroporid corals (Boström-Einarsson et al. 2020).

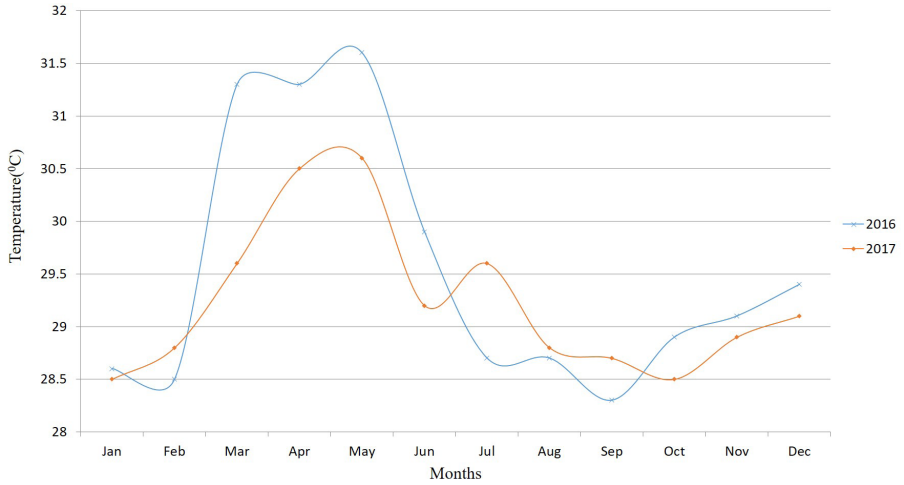

Figure 3. Sea water temperature (°C) around the transplantation site in Kavaratti Lagoon, Lakshadweep archipelago, from January 2016 until December 2018

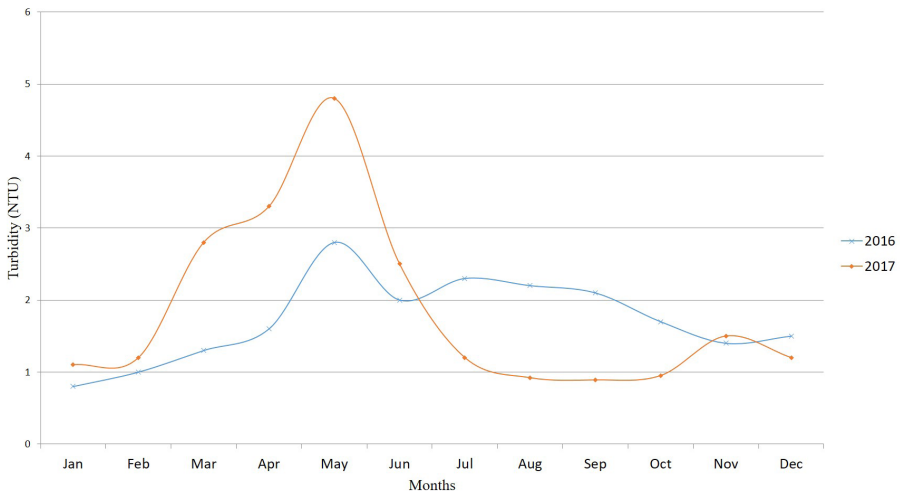

Figure 4. Turbidity around the transplantation site in Kavaratti Lagoon, Lakshadweep archipelago, from January 2016 until December 2018

Growth rates of coral in the present study are considered high compared to those observed in the Red Sea, and Pacific (Lizcano-Sandoval et al. 2018; Mahmoud et al. 2019). Varying growth rates have been reported for corals from many parts of the world, for example, coral Davis reef (0.67 cm/month; Oliver et al. 1983), Solitary Islands (0.80 mm/month; Harriott 1999), Thailand (0.28 cm/month; Putchim et al. 2008), Maldives (0.48 cm/month, Clark & Edwards 1995), and Gulf of Kachchh, India (0.33 cm/month; Kumar et al. 2016, Gulf of Mannar, India (0.79 cm/month; Ramesh et al. 2020). Idreesbabu et al. (2017) first studied the restoration of corals in the Lakshadweep archipelago and observed a mean growth of 14.85 cm/year for *Acropora muricata*, which was relatively lower than those observed in the present study (i.e., 15.55 cm/year). The comparatively higher growth rate obtained during the present study could be due to the better management and conducive physicochemical parameters prevalent in the region (Davidson et al. 2019).

The global mean survival rate of restored corals is 66% (Boström-Einarsson et al. 2020), with survival depending on various factors. Survival rates across all nursery fragments in our study ranged from 64% to 99%. Acroporid corals showed higher survival rates (between 90% and 99%) compared to non-acroporid corals (between 64% and 89%) indicating an improved survival rate compared to the global average (Figure 5). Our results reveal a higher success rate of transplantation efforts and good health of transplanted corals even after two years. This high survival is likely due to the size of coral fragments and coral species capable of

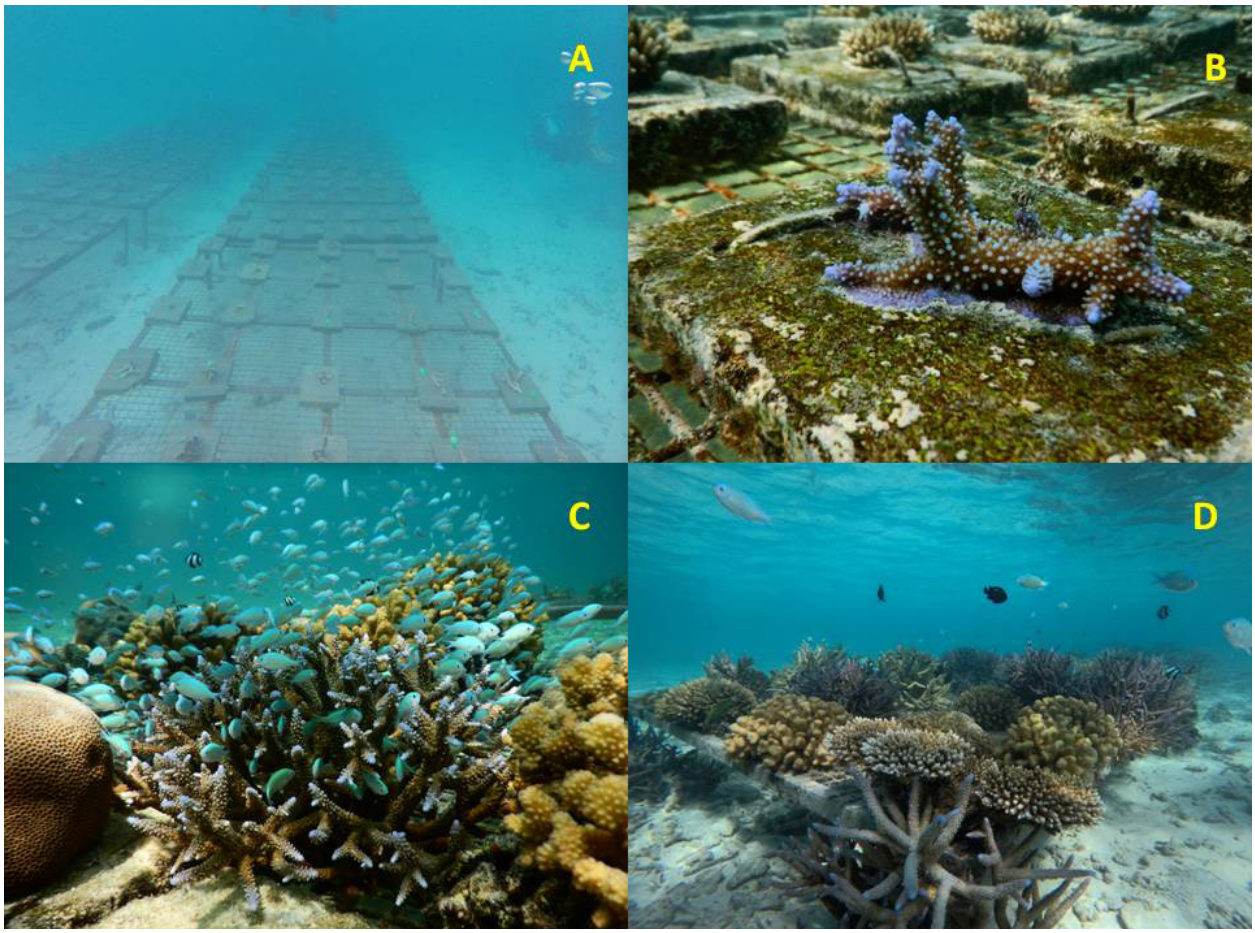

Image 3. A—Iron mesh with transplanted coral fragments deployed in the lagoon bed at Kavaratti, Lakshadweep archipelago | B—Secretion and deposition of $CaCO_3$ by *Acropora muricata* on cement slabs | C—Fish aggregation in the transplantation site | D—Well-developed coral colonies in the transplantation site after two years.

resisting environmental factors used for transplantation. Fragment size is a critical parameter to consider in reef restoration, as it influences the survival and growth of a coral transplant in the new environment (Sam et al. 2021). The initial size of the coral fragments used in our study ranged from 7 cm to 11 cm. Perhaps, the high survival rate obtained in this study indicates that we have used the optimal size of coral fragments for transplantation, as observed previously (Shafir et al. 2010).

Our study also highlights that successful coral transplantation depends on the selected species, and other key environmental factors, such as temperature and turbidity at the study site. In the Lakshadweep archipelago, the sea surface temperature usually increases between the summer months of March and May (Shenoi et al. 1999). In our study, the water temperature showed an increasing trend from March to May, with a gradual decline from the last week of May, due to the onset of the monsoon showers (Figure 3). Turbidity rates at the study sites increased from April and extended till August, mostly due to high wave action, high precipitation and water runoff during the monsoon. The data obtained from the ongoing coral reef monitoring program of Department of Science and Technology, shows that salinity, pH and dissolved oxygen (DO) in Kavaratti Island ranged 31.44–37.81 psu, 7.90–8.40, 3.02–4.88 ppm with average values of 35.14 psu, 8.18, and 3.94 ppm, respectively, which may also have influenced the coral transplantation. Physical parameters such as temperature, salinity, water motion, sedimentation and turbidity also influence the survival of transplanted coral, and reef health (Yap et al. 1998; Ferrier-Pages et al. 1999; Mohamed & Mohamed 2005; Ramesh et al. 2019; Howlett et al. 2021)

The diverse fish population at the transplantation site indicates that the 'site' mimics conditions on a natural reef (Rilov & Benayahu 2000), and offers a habitat which not only constitutes a shelter, but also acts as a potential breeding ground for fishes and other marine

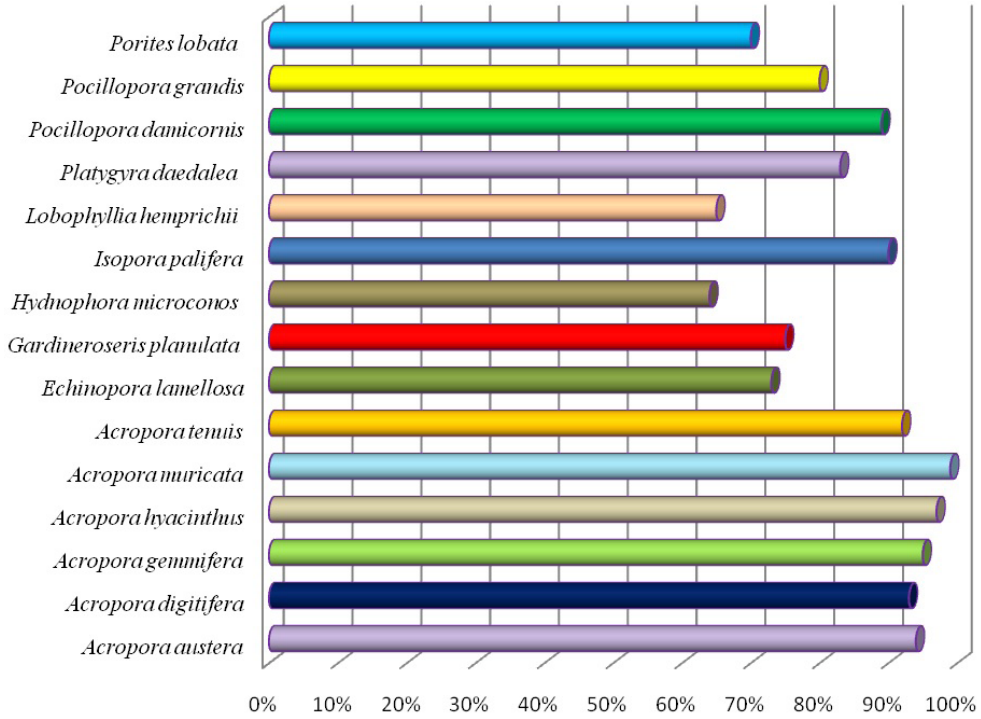

Figure 5. Percentage survival of various coral species in the transplantation site in Kavaratti lagoon, Lakshadweep archipelago, after two years.

Table 3. List of fish species observed at the coral transplantation site in Kavaratti Lagoon, Lakshadweep archipelago, and their numbers.

Family	Species	Number of fishes
Acanthuridae	*Acanthurus triostegus*	5
	Ctenochaetus striatus	20
Balistidae	*Rhinecanthus aculeatus*	2
Chaetodontidae	*Chaetodon trifascialis*	4
	Chaetodon auriga	2
	Chaetodon trifasciatus	10
	Chaetodon falcula	2
Holocentridae	*Sargocentron diadema*	3
	Neoniphon sammara	6
Labridae	*Thalassoma lunare*	2
	Halichoeres scapularis	5
	Gomphosus varius	2
	Labroides dimidiatus	2
Monacanthidae	*Oxymonacanthus longirostris*	3
Pomacentridae	*Chromis viridis*	415
	Dascyllus aruanus	30
	Chrysiptera unimaculata	5
	Centropyge multispinis	2
Scorpaenidae	*Pterois volitans*	4
Serranidae	*Epinephelus hexagonatus*	2
Zanclidae	*Zanclus cornutus*	2

organisms (Ulfah et al. 2020). Breeding habitats in the transplantation site were preferred for live baits such as *Chromis viridis* and *Dascyllus aruanus*, particularly among the branching coral of *Acropora* and *Pocillopora*. Populations of *Chromis viridis* and *Dascyllus aruanus* were higher than those of other fish species, indicating that the transplanted site serves as their favorable spawning ground (Goren 1992). As a fundamental objective, coral restoration targeted at reef recovery should consider re-establishing breeding populations of corals (Cruz & Harrison 2017).

Furthermore, an array of reef fishes consistently inhabits the transplantation site, which functions as a significant feeding area. This phenomenon can be attributed to the presence of diverse marine organisms including sponges, molluscs, and algae within the transplantation site. Consequently, numerous fish species reliant on these organisms for sustenance and other essential requirements are known to establish their habitats within this area. At the transplantation site, initial sightings included fish species from the family Labridae, such as *Thalassoma lunare* and *Halichoeres scapularis*. Labrids are invertebrate-eating fish species that are often found looking for food in concrete cracks or substrate surfaces. Similarly, herbivorous fish from the family Acanthuridae were observed throughout the transplantation site, exhibiting greater abundance

during the initial stages of transplantation. These fish primarily feed on algae present within the site and are frequently encountered close to transplantation sites. Acanthuridae contributes to a certain extent in mitigating algae proliferation, thus aiding in the facilitation of coral growth during the initial stages of transplantation. The abundance of herbivorous fish is a good indicator of a healthy reef (Abelson et al. 2016). Pomacentridae was another major family that had a high abundance in the transplantation site. Fishes of family Pomacentridae including *Chromis viridis* and *Dascyllus aruanus*, were predominantly observed following the establishment of branching corals such as *Acropora*. This trend can be attributed to the feeding behaviour of these fish, which utilize the water column for foraging, and seek refuge within coral reefs to evade attacks from carnivorous fish (Kuiter & Tonozuka 2001). The families Chaetodontidae, Balistidae, and Scorpaenidae were observed during the later stage of transplantation. The live coral cover condition at each age of transplantation shows the differences in the reef fish species community (Ulfah et al. 2020). This fish aggregation could also attract visitors and researchers to this location and highlight the importance of artificial reefs for marine restoration.

Coral transplantation tool can also be applied for underwater tourism while promoting a science-based coral reef management option for coral restoration (Edwards & Clark 1999). Transplantation of corals are also suggested to provide alternative livelihood (Young et al. 2012) for the fishing community (Bowden-Kerby 2003) as they depend on this site for the collection of live bait for tuna fishing and spearfishing during the southwest monsoon in this atoll. The transplantation site can, directly and indirectly, reduce the pressure on fragile natural coral growth through substitute aquaculture, community-based ecotourism, and increased environmental education, awareness and community stakeholder associations. The technique described in the article can easily be transferred to local communities, and imparting training to the fishers can be adopted using local expertise. Therefore, it is suggested that the development of coral transplantation sites can influence ecosystem services and indirectly benefit the livelihood of the fishing community. Therefore, the implementation of the coral restoration programme in all the islands of Lakshadweep is recommended for improved ecosystem services and enhanced livelihood opportunities.

CONCLUSION

The coral transplantation on artificial substrates in the shallow lagoon off the Lakshadweep archipelago has shown promising results in establishing a coral nursery, promoting coral growth and providing a habitat for marine life. The establishment of a coral nursery has led to increased fish aggregation, contributing to enhanced biodiversity and ecosystem resilience. These findings highlight the potential of this restoration technique as a valuable tool in reef conservation efforts for vulnerable ecosystems such as those found in the Lakshadweep archipelago. However, the use of artificial substrates instead of transplanting corals directly onto degraded reefs may present certain limitations, such as differences in the ecological interactions between the artificial and natural environments, potential changes in the structural complexity, and the long-term stability and durability of the artificial substrates. Additionally, the artificial substrates may not fully replicate the conditions necessary for the growth and survival of certain coral species. Continued monitoring and research are essential to assess the long-term effectiveness and sustainability of this approach.

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