



Rehabilitation of Coastal Habitat: A Vital Management Tool for Protecting Biodiversity and Livelihood against Climatic and Non-Climatic Factors

J.K. Patterson Edward*

Suganthi Devadason Marine Research Institute 44-Beach Road, Tuticorin - 628001, Tamil Nadu, India

Abstract. Coral reefs and seagrasses are important for biodiversity and livelihood but they are fast degrading owing to climatic and non-climatic factors. The impacts of climate change since 1998 and the effects of non-climatic factors, mainly destructive fishing practices, mining, pollution, and coastal development, have altered the community structure and health of corals and seagrasses. Low-tech and low-cost transplantation techniques have been successfully standardized and implemented in the Gulf of Mannar, southeast India. A coral rehabilitation technique, perfected in 2002, comprising selection of site, identification of suitable native species, precision in fragmentation, choosing fragment size, fixing positions, and effective monitoring protocols, resulted in good growth and a survival of 80.1%. The average annual growth was 13.5 cm in fast-growing branching corals and 1.8 cm in massive corals. There was also considerable increase in coral cover, recruit density, and population size of fish and associated macrofauna. Likewise, a rehabilitation program for seagrass was started in 2008. Seagrass shoots in the rehabilitated areas showed a good survival rate of 85.04% with increased biodiversity. Rehabilitation of degraded coral and seagrass areas is a viable management practice for the restoration of the ecosystem services like fishery, coastal protection, and tourism as well as enhancing ecosystem resilience.

Keywords. *corals, seagrasses, rehabilitation, transplantation, biodiversity, livelihood*

*Correspondence:
edwardjkpatterson@sdmri.in

Introduction

Coral reefs and seagrass beds are dynamic marine ecosystems that provide shelter to a wide range of ecologically and economically important organisms. Primary production, shoreline protection, carbon storage, and the like, are some of the other important ecosystem benefits bestowed by corals and seagrasses. In spite of their importance, these ecosystems have been allowed to be disturbed significantly by various natural and human-induced factors. It has been estimated that the world has lost half of its coral reefs in the past 30 years. It has also been reported that about 29% of global seagrass cover has already been lost since 1879 (Waycott et al., 2009). The unprecedented degradation of corals and seagrasses has prompted scientists and

managers around the world to take up rehabilitation activities in the degraded areas.

Methodologies for the rehabilitation of degraded coral reefs have advanced in the past two decades. There are several methods in reef rehabilitation, such as deployment of artificial reef structures (Pickering et al., 1998; Schillak et al., 2001), coral transplantation (Smith and Hughes, 1999), enhancing settlement and growth of corals by using feeble electrochemical means (Kihara et al., 2013), electrically stimulated coral growth enhancement (Goreau, 2014), larval ranching (Rinkevich, 2005), and establishment of low profile underwater nurseries (Rinkevich and Shafir,

2000). However, most of the rehabilitation techniques are expensive, labor-intensive, and unviable. Transplantation of coral fragments has been suggested as a useful technique for rehabilitating coral reefs for this technique and has been reported to yield desirable results in terms of reef recovery (Edwards and Clark, 1998; Harriott and Fisk, 1988; Okubo and Omori, 2001). Corals, being animals, can reproduce sexually and asexually. Transplantation of corals is based on their asexual reproduction through fragmentation. If a fragment of a coral broken from the donor colony finds a suitable substrate and environmental conditions, it can grow as a separate colony. The term coral transplantation refers to the transplantation of coral fragments onto artificially made substrates deployed underwater. The primary objectives of coral transplantation

are to improve (i) reef quality in terms of live coral cover, (ii) biodiversity, and (iii) topographic complexity (Edwards, 1998). Similarly, various rehabilitation techniques have been experimented to restore the seagrass meadows with varying success rates (Fonseca, 1992; Gordon, 1996; Seddon, 2004; Treat and Lewis, 2006). Over the years, there has been significant improvement in the techniques related to seagrass rehabilitation (Paling et al., 2009).

The Gulf of Mannar (GoM) on the southeast coast of India (Figure 1) is one of the four major coral reef areas in India with 117 corals species (Edward et al., 2007). The coral reefs in GoM are formed primarily around the 21 uninhabited coral islands that occur between Rameswaram and Tuticorin.

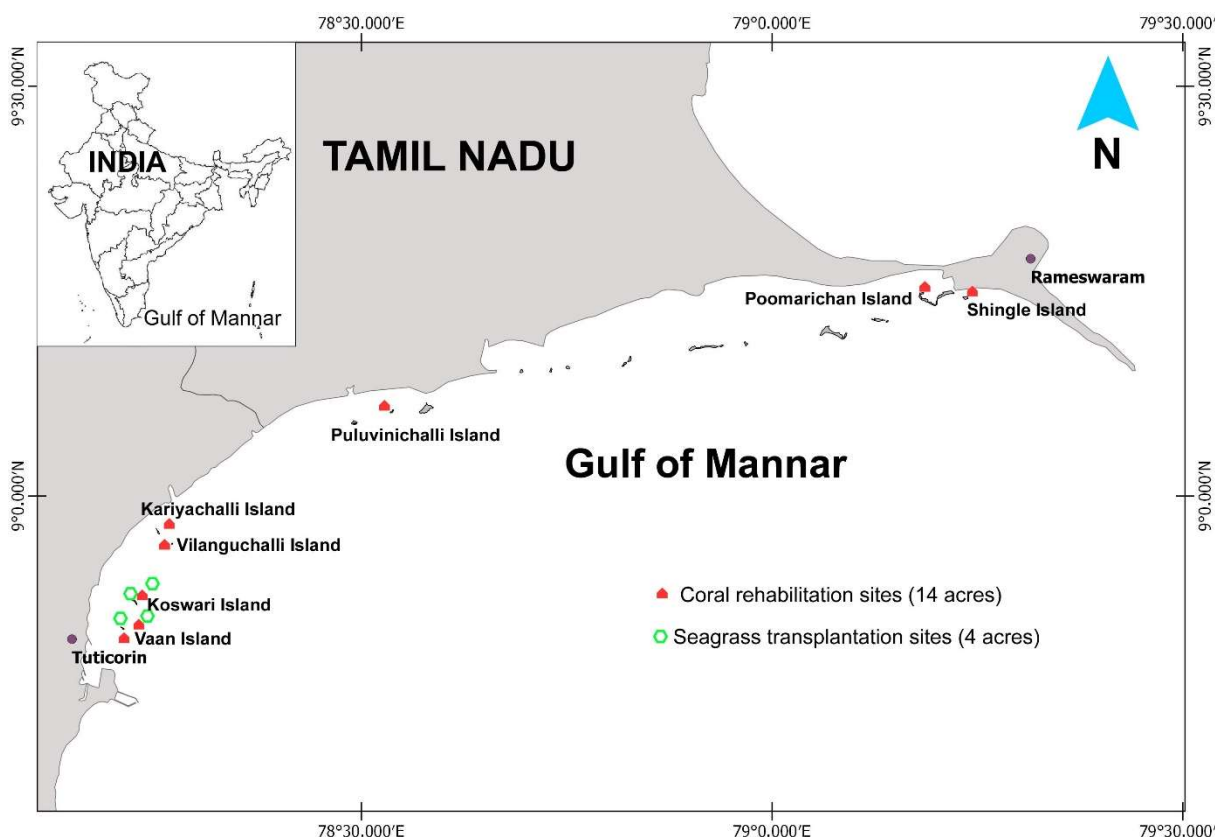


Figure 1: Map showing coral and rehabilitation sites in the Gulf of Mannar, southeast India

This area was declared as Gulf of Mannar Marine National Park by the Government of Tamil Nadu in 1986. For management purposes, the 21 islands of GoM have been put under three groups: Tuticorin group, Keelakarai group, and Mandapam group. In GoM, seagrass beds occur mainly in the region between the islands and the mainland, and also on the seaward sides of the islands, where seagrasses are seen as patches toward the open sea (Mathews et al., 2010). The coast of GoM is thickly populated and the livelihood of these traditional fisher folk depends mainly on the fishery resources associated with corals and seagrasses. GoM was once considered a biological paradise, but various human activities have put the ecosystem under stress with several biological resources dwindling. Coral mining, destructive fishing methods, climate change, and pollution have caused severe damage to the ecosystems of coral reef and seagrass. Massive corals were also used for the construction of building and roads during the 1960s. Hence, rehabilitation of corals and seagrasses using low-tech and low-cost methods is considered the most important management tool not only for the conservation of these fragile ecosystems, but also for the protection of biodiversity and the livelihood of the dependent people.

Materials and Methods

Coral Rehabilitation

Substrates

Identifying and designing proper artificial substrates is very important for the success of the coral rehabilitation program. Several substrates such as cement slabs, stones, and clay pots were tried initially. Suspension and rope culture methods were also undertaken in the preliminary experiments. In addition, fish houses constructed with dead corals from old building debris were also tried out. Based on the promising results, two types of artificial substrates were used in GoM which are concrete frames with slabs and fish houses. The structure of the concrete frame has been designed by Suganthi Devadason Marine Research Institute (SDMRI) after several experimentations in GoM. Concrete frames of the dimensions 1 m x 1 m x 0.25 m were used along

with fish houses made of dead coral debris with dimensions approx. 1 m dia. X 0.5 m height. Dead corals for fish houses were obtained from demolished old houses. Beginning in 2002, these structures were deployed in different parts of GoM. Deployment of these frames at proper sites was done before the fragments were transplanted onto concrete frames. Cement slabs of 20 cm x 5 cm x 15 cm were used for fixing the coral fragments and the fragments were directly tied onto fish houses underwater.

Site selection

The selection of ideal sites is a key factor in getting good results in rehabilitation. Other considerations are the general extant conditions for coral growth and the availability of donor corals in the vicinity of the proposed transplantation site. The donor sites were selected from where the corals were comparatively healthy and had a good live coral cover.

Substrate transportation

Each substrate (concrete frame/fish house) weighed about 80–100 kg. This mass was necessary to maintain stability. The substrates were transported from the place of construction to the shore by trucks. From the seashore, the substrates were moved to the rehabilitation sites using a raft made of bamboo sticks. The raft was pulled by a mechanized boat. At the rehabilitation site, the structures were lowered to the ocean floor with the help of ropes tied to the frames/fish houses. Then scuba divers went underwater to arrange them in a proper order. The substrates were arranged with an interval of 1 to 2 meters between one another; this space was left for the coral growth and for the easy flow of current.

Species selection

Selection of suitable species is also a critical step in rehabilitation, for the probable size of the live coral cover depends on the species involved. Successful transplantation can be done only with the native species, and the selected species should be healthy and abundant in the donor site. The following are the species selected for coral rehabilitation in GoM: *Acropora nobilis*, *A. formosa*, *A.*

intermedia, *A. cytherea*, *A. valida*, *Montipora fo-liosa*, *Turbinaria mesenterina*, *T. peltata*, *Favia pallida*, and *Porites solida*.

Coral fragment collection

Scuba divers involved in the collection of fragments handled them with great care. Fragmentation did not exceed 3–5% of the donor colony; this limit is to reduce the stress on the donor colony. A hammer and chisel were used for the fragmentation under the water. The removed fragments were placed in plastic baskets and taken to the boat, where they were immediately transferred to big plastic tubs with sea water aerated with portable aerators. Precision and care were taken during fragmentation and transportation of fragments from the donor site. The plastic tubs with coral fragments were covered with cloths to avoid direct sunlight and were taken immediately to the rehabilitation site. The sea water in the tubs was changed at regular intervals in order to reduce the stress, and the levels of temperature and salinity were monitored.

Transplantation

Attaching the coral fragments onto the cement slabs was done during the transportation. The collected coral fragments were first cut to the desirable size (that is > 8 cm) using a bone cutter. Each fragment was attached onto a cement slab in a horizontal orientation using nylon rope, such that the largest part of it was in contact with the substrate and most of the polyps were oriented upward in vertical position of the fragment. The fixed fragments were then transferred to a fresh sea water tub. On reaching the rehabilitation site, the fragments tied with the cement slabs were immediately taken into the water in plastic trays by the scuba divers for transplantation. The slabs were arranged over the frames with a gap of about 5 cm between them. Ten slabs with fragments were placed on one concrete substrate; they were tied to the frame with the help of nylon ropes to ensure that they were not dislodged by the waves and currents. Onto the fish houses, fragments were directly tied under the water using nylon ropes.

Monitoring and maintenance

For a successful rehabilitation of corals, monitoring and maintenance of the rehabilitated sites

are no less important than the other steps. Survival and growth of the transplanted corals were regularly monitored. The associated organisms such as fishes and macrofauna were also monitored regularly. Signs of bleaching and disease outbreaks were looked for very carefully on the transplanted coral colonies. A regular monitoring of water quality conditions was also conducted.

Marine algae can attach themselves to the artificial substrates, and because of their fast growth rate, the algae may suffocate the transplanted coral fragments and kill them. Hence, the algae frequently were monitored and removed. If any fishing nets were found entangled in the concrete frames or transplanted corals, they were removed immediately as they would keep on damaging the corals mechanically. Other mechanical damages, like the dislodgement of slabs with fragments, were monitored too and they were set right or replaced immediately.

Seagrass Rehabilitation

Initial experimentation

Experimentation was done initially to identify the most feasible method in GoM, including plug, staple, and manual transplantation of sprigs. In the plug method, seagrasses with attached sediment were harvested using core tubes and transported with the tube to the rehabilitation site. At the planting site, a hole was made to accommodate the planting plug. In the staple method, seagrasses were dug up using shovels, and the attached sediment was removed from the roots and rhizomes. Seagrasses were then attached to staples by inserting the root-rhizome portion, and the staples were in turn inserted into the sediment so that the roots and rhizomes remained buried into the sediment surface (Christensen et al., 2004). Manual transplantation of sprigs (Perrow et al., 2002) was found to be the best choice for seagrass rehabilitation in GoM.

Donor sites

Donor sites were always selected very close to the rehabilitation site so that the sprigs can have similar environmental conditions. To reduce the stress to the donor sites and to allow the recovery, collection of sprigs from the nearby dense seagrass meadows was restricted to less than

5%. Three seagrass species abundant in GoM viz. *Cymodocea serrulata*, *Thalassia hemprichii*, and *Syringodium isoetifolium* (Mathews et al., 2010) were used for rehabilitation.

Manual transplantation of sprigs

Mature seagrass sprigs were collected manually in mesh bags by scuba divers. The sprigs were thoroughly washed in seawater to free them from sediment, and were then transferred to large containers filled with seawater. Apical shoots with intact roots were attached at regular intervals to a biodegradable jute twine, and the twine was tied to a PVC quadrat of 1 m² area. Six rows of such jute twines were tied to each quadrat, and each row had 20 shoots. Thus, there were a total of 120 shoots in a quadrat. The quadrats were pre-drilled to allow the sea water to enter and to make them negatively buoyant. Then, these quadrats with sprigs were immediately taken underwater and fixed at the rehabilitation site. Hook-shaped iron clamps of 30 cm length were used for anchoring the frames in the sediment. These quadrats and threads helped in keeping the shoots intact and also from being washed away by the waves, tides, and current. They were left until the shoots were firmly attached to the sediments (Estrella, 2004; Fonseca et al., 1998). It was ensured that all shoots tied to jute ropes were kept attached to the seafloor.

Monitoring and maintenance

After the seagrass plants attached themselves into the soil, seagrass cover and shoot density were monitored regularly. A regular assessment of fishes and benthic macrofauna was also carried out. Monitoring of environmental parameters, a very important input to understand the status of transplanted seagrass plants, was done. The mandatory initial maintenance measure of removing the solid wastes, torn pieces of nets, and seaweeds was performed too.

Results and Discussion

Conservation of marine ecosystems is linked to the sustained livelihood of a dependent community. In India, there was not much focus and interest on rehabilitation research until the Indian Ocean Tsunami in 2004. Coral rehabilitation

since 2002 and seagrass transplantation since 2008 by Suganthi Devadason Marine Research Institute (SDMRI) in GoM are the first and successful attempts in Indian waters. SDMRI has standardized the viable, low-tech, and low-cost rehabilitation techniques for large-scale rehabilitation of corals and seagrasses (Patterson et al., 2005; 2008). Coral and seagrass rehabilitation has been carried out within 4–14 acres of degraded areas in various locations of GoM since 2002. Long-term monitoring of rehabilitation measures, not less than 3 years for coral rehabilitation and 2 years for seagrass rehabilitation, is also done by SDMRI to understand the later well-being of the transplants.

The coastal biodiversity of GoM has been subject to threats by various climatic and non-climatic factors. Coral reefs of GoM have been disturbed by coral mining, destructive fishing activities, pollution, bleaching, disease outbreaks, bio-invasion, space competition, etc. (Edward et al., 2012). Coral bleaching in 2010 and 2016 caused a massive mortality among the corals of GoM; the rates of mortality in the two events respectively are 9.7% and 16.2% (Edward et al., 2012; Edward et al., 2017). Coral cover has been fluctuating in GoM since 2003–2005, when it was 36.98% and increased to 42.85% in 2009 after the halt of coral mining, and then went down to 33.2% in 2010 because of the bleaching mortality. Again, it increased gradually to 38.86% in 2015 before going down to 22.69% in 2016 because of bleaching mortality (Edward et al., 2017). Recovery by natural coral recruitment is a long process; moreover, such recovery is often beset with disturbances and problems of space competitors. Hence, rehabilitation measures are required to increase the live coral cover with resilient and resistant native coral species. Coral transplantation facilitates natural recovery of the damaged reef sites (Edwards and Clark, 1998).

Unfortunately, most of the rehabilitation measures are expensive and labor intensive and can still result in high mortality not only in the coral transplants but also in the natural donor corals. The technique used for coral rehabilitation in GoM is cost-effective and offers a significantly higher survival rate. An average survival

rate of 80.1% has been recorded for coral transplants from various parts of GoM during the monitoring period. Among the transplanted coral species, *A. nobilis* exhibited the highest survival rate of 89.35% followed by *A. intermedia* with 89.25%. *P. solida* and *F. pallida* showed lower survival rates at 63.28 and 71.29% respectively. Survival rates of *A. formosa*, *A. cytherea*, *A. valida*, *Montipora foliosa*, *T. mesenterina*, and *T. peltata* were 87.64%, 86.47%, 80.15%, 80.12%, 79.26%, and 74.15% respectively (Figure 2). Survival of the coral transplants is the prime and utmost consideration in the success of any coral transplantation mission.

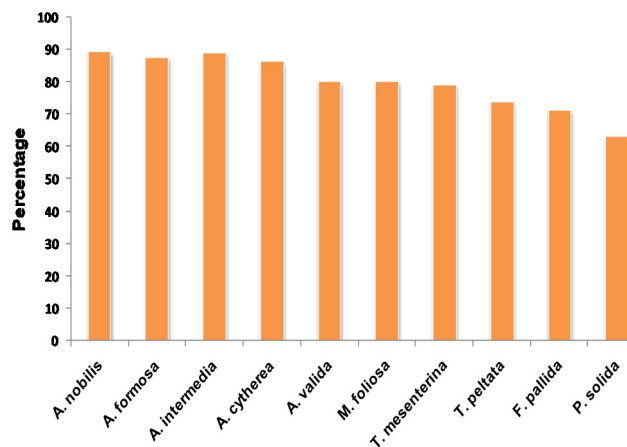


Figure 2: Survival of coral transplants

On reaching a certain size, the transplanted fragments are no more vulnerable to the high risk of mortality (Connell, 1973; Highsmith, 1982). Growth rates of the transplanted corals in GoM are significantly higher. Among the transplanted corals, branching type corals showed comparatively higher growth rates with an average of 13.5 cm/year. *A. intermedia* had the highest growth rate at 17.63 cm/year followed by *A. formosa* and *A. cytherea* with their respective rates being 13.28 cm and 13.28 cm/year. Foliose type corals such as *T. mesenterina*, *T. peltata*, and *M. foliosa* showed an average growth rate of 4.24 cm/year; and massive corals such as *F. pallida* and *P. solida* showed an average growth rate of 1.8 cm/year (Figure 3).

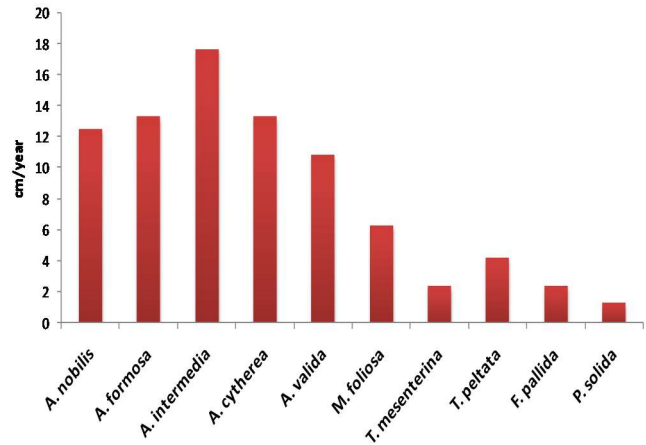


Figure 3: Annual average growth of coral transplants

Ideally in a successful transplantation project, the transplanted corals should survive and grow in a manner similar to that of the naturally occurring corals (Yap et al., 1992). This has become true in GoM as the transplants have started growing in a manner similar to the natural corals (Plates 1–2). It has been reported that coral fragments reallocate energy resources after fragmentation, and there is infertility for a period of time (Nonaka et al., 2003). However, transplants in GoM have grown sufficiently so as to take part in sexual reproduction. Successful gametogenic cycle and spawning have also been recorded from the restored coral colonies in GoM (Raj et al., 2015).

Coral recruitment is widely acknowledged as one of the most important processes in the maintenance of coral reef systems, especially in their recovery and replenishment following disturbances (Glassom, 2006). Artificial substrates used for coral transplantation in GoM have also served as coral recruitment substrates. Recruits of the following seven coral genera were observed on these substrates: *Acropora*, *Pocillopora*, *Montipora*, *Favia*, *Favites*, *Porites*, and *Turbinaria*. Of them, *Acropora* had the highest recruit densities with 2.88 no.module⁻¹ and *Montipora* had the next best value of 2.19 (Figure 4).



Plate 1: Coral rehabilitation on concrete frames with slabs



Plate 2: Coral rehabilitation on fish houses

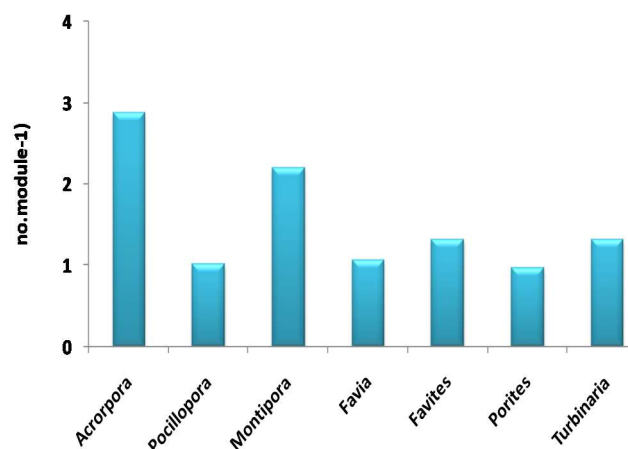


Figure 4: Average coral recruit density on rehabilitation substrates

Overgrown branches of the transplanted coral colonies are sometimes fragmented by strong waves and currents. These branches also have grown independently near the substrates through asexual reproduction and thus increased the live coral cover. With the increase of live coral cover, other organisms such as macrofauna and fish are attracted to the rehabilitation

sites. The average densities of major benthic macrofauna were 3.15, 2.42, 1.85, 1.32, and 0.98 $5m^{-2}$ respectively for molluscs, echinoderms, ascidians, sea anemones, and sponges (Figure 5). Fishes also started occupying the rehabilitation sites; *Lutjanus* (32.89 $60m^{-2}$) and *Scarus* (30.28 $60m^{-2}$) were the dominant genera encountered near the rehabilitation sites in GoM (Figure 6).

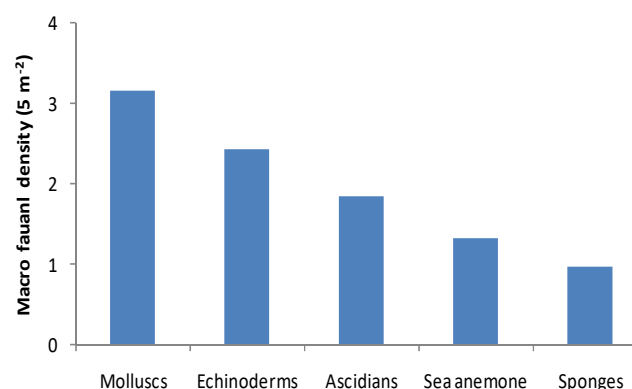


Figure 5: Average macrofaunal density in the coral rehabilitation sites

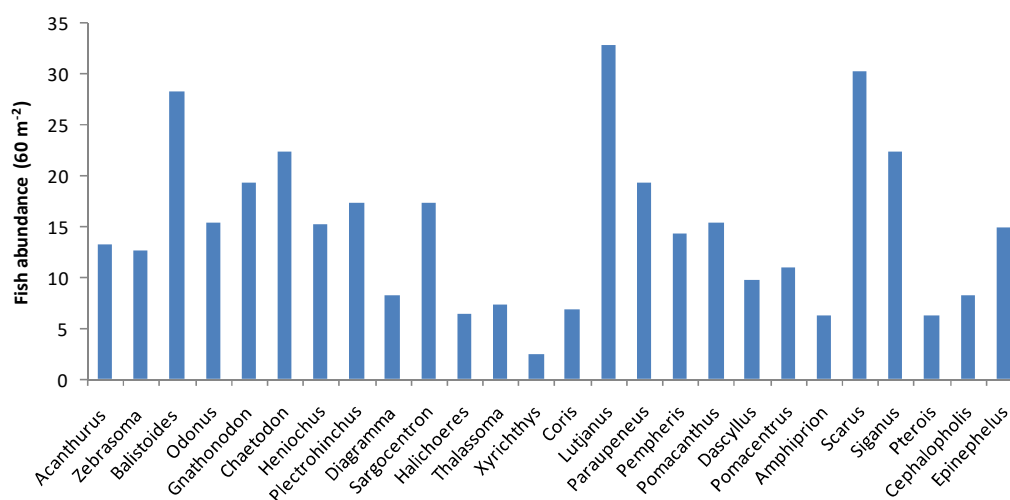


Figure 6: Average commonly occurring fish abundance in the coral rehabilitation sites

Like coral reefs, seagrass beds in GoM have also been significantly disturbed by destructive fishing practices, predominantly by bottom trawling. Three types of bottom trawling activities are encountered in GoM, namely mechanized trawling by big trawlers, push net operation, and shore seine operation (Raj et al., 2017). Furthermore, bottom laid gill nets, boat anchoring, invasion of exotic seaweed, pollution, and coastal developmental activities are the other threats causing damage to the seagrass beds of GoM (Mathews et al., 2010). Hence, rehabilitation of seagrasses is necessary to tackle the increasing threats. SDMRI initiated the seagrass rehabilitation activities in 2008 and perfected the technique to suit the conditions of GoM.

Three species of seagrasses, namely *Cymodocea serrulata*, *Thalassia hemprichii*, and *Syringodium isoetifolium*, were transplanted at different locations of GoM. The average rate of survival of seagrass plants was 85.04%. *C. serrulata* had the highest survival rate with 87.64% followed by *S. isoetifolium* with 86.52%, while *T. hemprichii* had a survival rate of 80.96% (Figure 7). Shoot density was also the highest for *C. serrulata* at 110.32 m⁻² followed by *T. hemprichii* and *S. isoetifolium* at 86.42 and 72.96 m⁻², respectively (Figure 8).

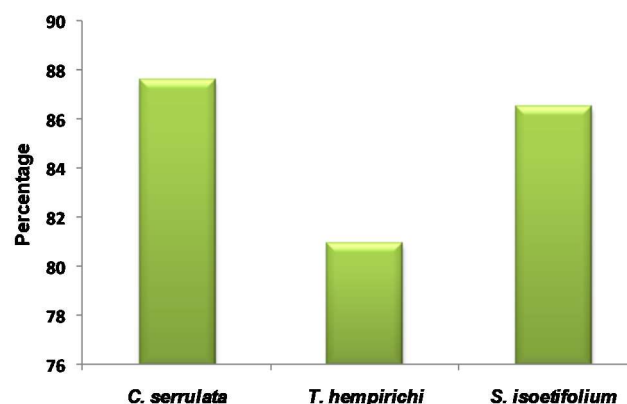


Figure 7: Survival of transplanted seagrass plants after 2 years

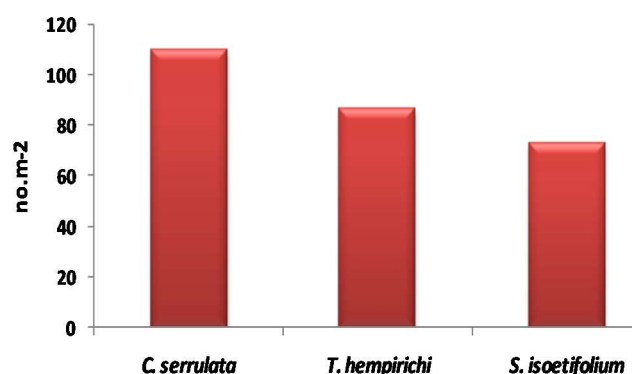


Figure 8: Average shoot density of transplanted seagrass plants after 2 years

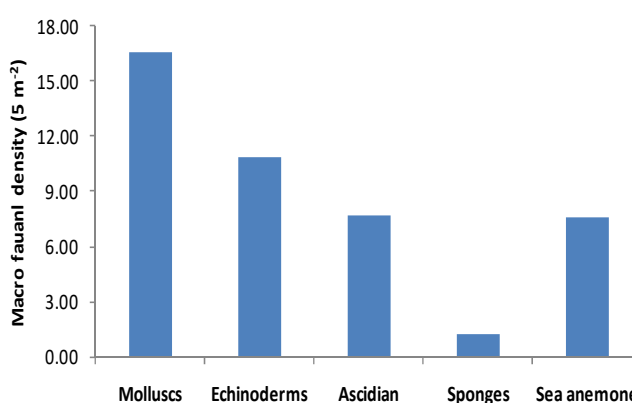


Figure 9: Average macrofaunal density in the seagrass rehabilitation sites

Among the benthic macrofauna, mollusks followed by echinoderms were the dominant categories with 16.62 and 10.89 5m⁻², respectively, while densities of ascidians, sponges, and sea anemones were 7.69, 1.2 and 7.59 5m⁻², respectively (Figure 9). *Lutjanus* (26.87 60m⁻²), *Terapon* (21.68 60m⁻²), and *Parupeneus* (20.63 60m⁻²) were the common fish genera observed in the seagrass rehabilitation sites in GoM (Figure 10).

Many seagrass rehabilitation activities have yielded poor results because of various factors such as poor site selection, high sedimentation, reduced light, strong waves and currents, animal foraging, and the like (Treat and Lewis, 2006).

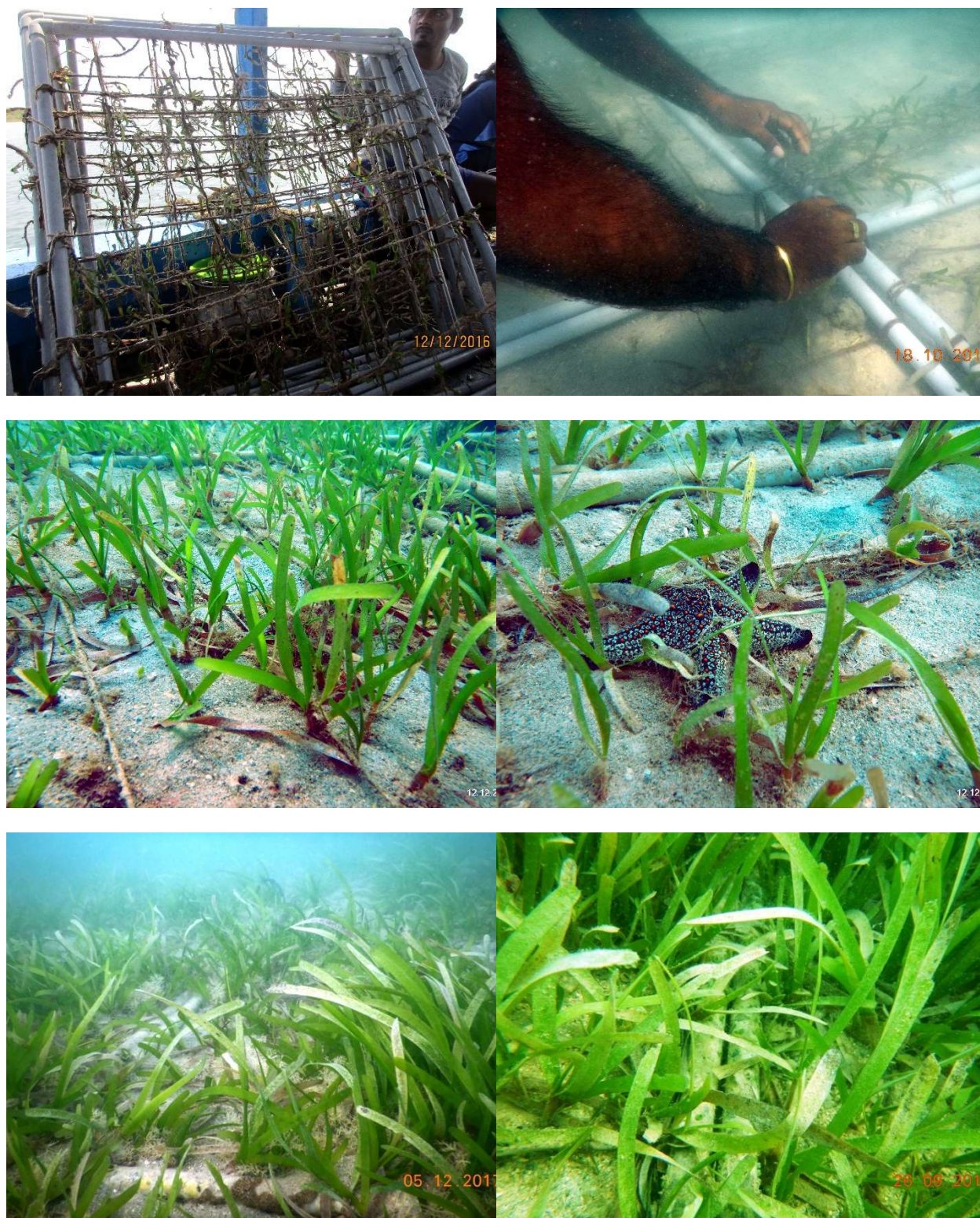


Plate 3: Seagrass rehabilitation using PVC frames

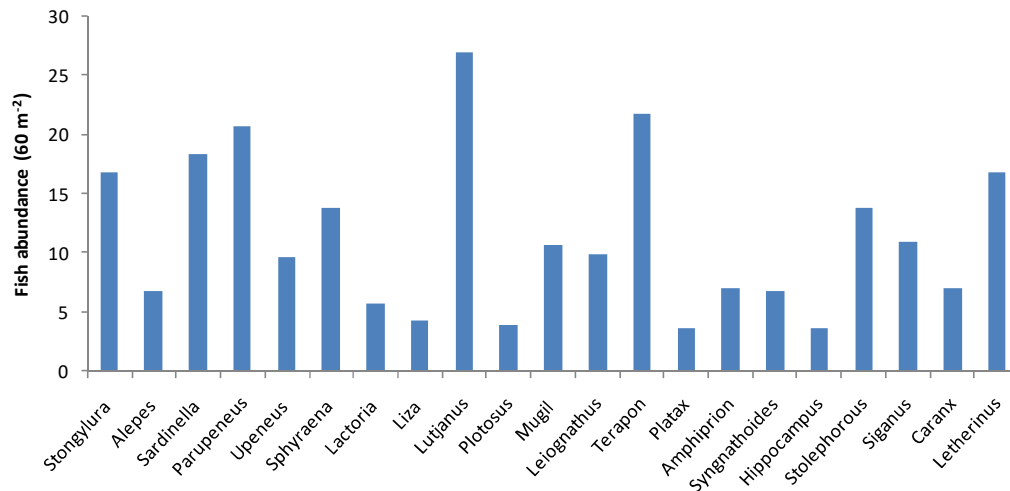


Figure 10: Average commonly occurring fish abundance in the seagrass rehabilitation sites

In GoM, rehabilitation of seagrasses has met with considerable success in terms of survival and increase of shoot density. Poor water quality disturbs the growth and survival of transplanted seagrasses (Orth and Moore, 1982; Treat and Lewis, 2006). In GoM, water quality is conducive to successful seagrass transplantation. The rehabilitation sites were barren sandy areas before the transplantation and have now become luxuriant seagrass beds capable of providing such ecosystem services as the nearby natural seagrass beds are (Plate 3). The population of the associated organisms such as fish and other macrofauna too increased with the increase of seagrass cover. It has been reported that increase in seagrass cover triggers an increase in fish abundance (Hemminga and Duarte, 2000).

Global climate change has impacted all the marine habitats around the world including coral reefs and seagrasses. Sea surface temperature, in line with the third global coral bleaching event, was very high in GoM during the summer of 2016, resulting in severe coral bleaching and subsequent mortality (Edward et al., 2017), although no obvious impact was observed on seagrass beds. Such disasters and consequent mortalities are expected in future also. Therefore, it is imperative that the human-induced threats, such as destructive fishing practices, should be checked to conserve the fragile marine habitats. The rehabilitation techniques elaborated in this study have been tested by SDMRI for many years since 2002, in the case of corals, and

since 2008, in the case of seagrasses; and they have been found to be much viable. Considering the enormous threats to corals and seagrasses, large-scale rehabilitation activities have become necessary to protect the coral biodiversity, to enhance sustained livelihood, and to support reef based eco-tourism activities. Coasts with intense developmental activities could also consider these viable low-tech and low-cost rehabilitation techniques to keep the native biodiversity intact and also to promote eco-tourism activities, allowing the natural reef and seagrass areas to thrive undisturbed.

A successful coral rehabilitation depends on the selection of a suitable site; designing of appropriate substrate to avoid sedimentation as well as to assist the fragments to attach quickly; selection of donor coral site with healthy climate-resistant and resilient native species; and determination of proper fragment size. The importance of regular monitoring and maintenance hardly needs emphasis. Timely intervention such as replacement of fragments when they are subject to local disturbances is required as much as identifying and taking remedial measures in the initial stage of rehabilitation. Successful seagrass rehabilitation is similarly dependent on the selection of suitable site, suitable substrate, healthy donor seagrass beds, monitoring, and maintenance to replace the disturbed frames with shoots in the initial stage. The techniques practiced in GoM are cost-effective and use simple technology but are with high success rates, and they can be adopted

in similar environs to enhance the live coral and seagrass cover, to protect biodiversity, to support eco-tourism, and to increase sustained livelihood options.

Acknowledgment

The authors acknowledge their indebtedness to the Ministry of Environment, Forest and Climate

Change, Government of India; Coral Reef Degradation in Indian Ocean (CORDIO); Tamil Nadu Forest Department, Tamil Nadu Environment Department; Gulf of Mannar Biosphere Reserve Trust, IUCN India, and GIZ India for funding support. They express their thanks to Tamil Nadu Forest Department and V.O. Chidambaranar Port Trust, Tuticorin, for research permissions.

References

- Christensen, P.B., E.D. Almela and O. Diekmann. (2004). "Can transplanting accelerate the recovery of seagrasses? J.; Duarte, C.M.; Krause-Jensen, D.; Greve, T.M. (Eds): European seagrasses: an introduction to monitoring and management. The monitoring and management of European seagrasses", EVK3-CT-2000-00044. *Borum*. 77-8
- Connell, J. E. (1973). Population ecology of reef building corals. Pages 205– 245 in Jones, O. A. and Endeans, R. (eds.), *Biology and geology of coral reefs*. Academic Press, London
- Edward, J. K. P., Mathews, G., Patterson, J. Wilhelmsson, D., Tamelander J. and Linden, O., (2007). Coral reefs of the Gulf of Mannar, Southeastern India – distribution, diversity and status. SDMRI Special publication no.12, 113p
- Edward, J. K. P., Mathews, G., Raj, K. D., Thinesh, T., Patterson, J., Tamelander, J., Wilhelmsson, D. (2012). Coral reefs of Gulf of Mannar, India - signs of resilience. In *Proceedings of the 12th International Coral Reef Symposium*, Cairns, Australia, 2012
- Edward JKP, Mathews G, Raj KD, Laju RL, Bharath MS, Arasamuthu A, Kumar PD, Bilgi DS, Malleshappa H (2017) "Coral mortality in Gulf of Mannar, Southeastern India, due to bleaching caused by elevated sea temperature in 2016", *Current Science*, In Press
- Edwards, A.J. and S. Clark. (1998). "Coral transplantation: A useful management tool or misguided meddling?" *Marine Pollution Bulletin*, 37: 474-487
- Edwards, A. J. (1998). "Coral transplantation: A useful management tool or misguided meddling?", *Marine Pollution Bulletin*. 37: 474-487
- Estrella, B. T. (2004). Hub Line Impact Assessment, Mitigation and Restoration. Annual Progress Report of the Massachusetts Division of Marine Fisheries to the Executive Office of Environmental Affairs. 58p
- Fonseca, M.S. (1992). Restoring seagrass systems in the United States. In: *Thayer, G.W. (Ed.), Restoring the Nation's Marine Environment*. Maryland Sea Grant College, College Park, Md., *Publ. UM-SG-TS*. 92-06
- Fonseca, M.S, W.J. Kenworthy and G.W. Thayer. (1998). Guidelines for mitigation and restoration of Seagrass in the United States and Adjacent Waters, *NOAA COP/Decision Analysis Series* 12: 222
- Glassom, D., Celliers, L. and Schleyer, M. H. (2006). "Coral recruitment patterns at Sodwana Bay, South Africa", *Coral Reefs*. 25(3): 485-492
- Gordon, D.M. (1996). Status of seagrass restoration: *Review of international literature*. Le Provost, Dames and Moore, Perth, Western Australia
- Goreau, T.J., (2014). "Electrical Stimulation Greatly Increases Settlement, Growth, Survival, and Stress Resistance of Marine Organisms", *Natural Resources*, 5, 527-537
- Harriott, V. J. and Fisk, D. A. (1988). Coral transplantation as a reef management option. *Proceedings of the Sixth International Coral Reef Symposium*. 2: 375-379

- Hemminga, M.A. and C.M. Duarte (2000) *Seagrass ecology*. Cambridge University Press. pp.298
- Highsmith, R. C. (1982). "Reproduction by fragmentation in corals", *Marine Ecology Progress Series*. 7:207-226
- Kazuyoshi Kihara, Hiroki Taniguchi, Yukio Koiuchi, Satoru Yamamoto, Yasufumi Kondo, and Yasushi Hosokawa (2013). "Enhancing settlement and growth of corals using feeble electrochemical method. Galaxea", *Journal of Coral Reef Studies* (Special Issue): 323 -329 (2013)
- Mathews, G, K.D. Raj, T. Thinesh, S. Rajesh, P. Jamila and J.K.P. Edward. (2010). "Preliminary baseline data on marine flora and fauna of Kundankulam coast, Gulf of Mannar, Southeast coast of India", *South Indian Coastal and Marine Bulletin* 2: 1-5
- Nonaka M, Baird AH, Kamiki T, Yamamoto HH, (2003) "Reseeding the reefs of Okinawa with the larvae of captive-bred corals", *Coral Reefs*, 22: 34
- Okubo, N. and Omori, M. (2001). "The review of coral transplantation around the world" (in Japanese with English abstract). *Galaxea*. 3: 31- 40
- Orth, R.J. and Moore, K.A. (1982). The biology and propagation of *Zostera marina*, eelgrass, in the Chesapeake Bay, Virginia. Final Report U.S. EPA. Grant No. R805953, Washington, DC. pp.187
- Paling, E.I., Fonseca, M., Marieke, M., Katwijk, V. and Keulen, M.V. (2009). Seagrass restoration, Coastal Wetlands – An integrated ecosystem approach, *Elsevier*, 687-713
- Patterson Edward, J.K., Jamila Patterson, Mathews, G., and Dan Wilhelmsson, (2005). Awareness raising and feasibility of reef restoration through coral transplantation in Tuticorin, Gulf of Mannar, India. CORDIO Status Report, 243-251
- Patterson Edward, J.K., Jamila Patterson and Dan Wilhelmsson (2008). Conservation and management of coral reefs and seagrasses of the Gulf of Mannar and Palk Bay, Southeastern India: Significant contributions from SDMRI during 2000-2008. SDMRI Special Research Publication No.13, 35 p
- Perrow, M.R. and Anthony J. (2002). Davy, eds. *Handbook of ecological restoration*. vol. 2. Cambridge University Press 618
- Pickering, H., Whitmarsh, D. and Jensen, A. (1998). "Artificial reefs as a tool to aid rehabilitation of coastal ecosystems investigating potential", *Marine Pollution Bulletin*. 37: 505-514
- Raj, K. D., Mathews, G., Edward, J. K. P. (2015). "Reproductive success of restored coral colonies in Vaan Island, Gulf of Mannar, Southeastern India", *Indian J. Geomarine Sci.*, 44(4): 589-598
- Raj, K. D., Mathews, G., Bharath, M. S., Sawant, R. D., Bhawe, V., Apte, D., Vasudevan, N., Edward, J. K. P. (2017). "Climate change induced coral bleaching in Malvan Marine Sanctuary, Maharashtra, Arabian Sea", *Current Science*, 114(2): 384-387
- Rinkevich, B. (2005). "Conservation of Coral Reefs through Active Restoration Measures: Recent Approaches and Last Decade Progress" *Environ. Sci. Technol.*, 39 (12), pp 4333-4342
- Rinkevich, B. and Shafir, S. (2000). "Ex situ culture of colonial marine ornamental invertebrates: concepts for demonstration", *Aquarium Science and Conservation*. 2: 237-250
- Schillak, L. Ammar, M. S. A. and Müller, W. E. G., (2001). Transplantation of coral species to electrochemical produced hard substrata: *Stylophora pistillata* (Esper, 1797) and *Acropora humilis* Dana, 1846. *ACP-EU Fisheries Research Report*, 10: 68-84 Mombasa, Kenya, 19-22 June 2000, Brussels
- Seddon, S. (2004). "Going with the flow: facilitating seagrass rehabilitation", *Ecol. Manage. Restor.* 5: 167-176
- Smith, L. D. and Hughes, T. P. (1999), "An experimental assessment of survival, re-attachment and fecundity of coral fragments", *Journal of*

- Experimental Marine Biology and Ecology*. 235: 147-164
- Treat, S.F. and Lewis III, R.R. (2006). Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11-12, 2003. Lewis Environmental Services, Valrico, Florida
- Waycott, M., C.M. Duarte, T.J. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik and G.A. Kendrick. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences* 106: 12377-12381
- Yap, H. T., Alino, P. M. and Gomez, E. D. (1992). "Trends in growth and mortality of three coral species (Anthozoa: Scleractinia), including effects of transplantation", *Mar Ecol Prog Ser*. 83: 91-101