Reproductive success of restored coral colonies in Vaan Island, Gulf of Mannar, Southeastern India

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Present study consists reproductive behaviors of natural and transplanted acroporan corals in Vaan Island of the Gulf of Mannar. Single reproductive season per year and reproductive synchrony have been observed during the study period between 2008 and 2010 among the monitored Acropora species in both natural and transplanted colonies. Studies on the gametogenic cycle in three species, Acropora intermedia, A. nobilis and A. cytherea showed a single annual cycle of gametogenesis. Patterns of oogenesis, spermatogenesis and fecundity were almost similar between the three species and between natural and restored colonies. Multi-specific synchronous spawning was observed among the acroporans from both natural and restored colonies during March in all the study years. It was obvious that restored corals involve in the sexual reproduction effectively in Vaan Island exactly as the natural corals. Hence restoration through fragment transplantation is a successful option to employ in any degraded reef.

Keywords: Acropora, Vaan Island, Gulf of Mannar, Restored, Transplanted

Introduction

Coral transplantation has been widely accepted as an effective mean of coral restoration and which has been suggested as a viable methodology for expediting the recovery of damaged or degraded reef area¹. The measure of coral transplantation is probably the most common management practice used to facilitate natural recovery of damaged reef sites². The primary objectives of coral transplantation are to improve (i) reef quality in terms of live coral cover, (ii) biodiversity and (iii) topographic complexity³. The transplantation of corals to an artificial habitat provides a unique opportunity for a detailed examination of their optimal niches by means of survivorship and growth rates⁴. Studies on survivorship and the reproductive ability of transplanted coral fragments are important for coral reef restoration⁵-⁶. Survival and growth of the transplanted coral fragments alone cannot make the restoration process a success. It can be called as success only after confirming them to act as the natural corals do. Knowledge of coral reproductive biology and the associated processes of dispersal and recruitment is an essential prerequisite for ecological studies of coral populations and communities. Research on these topics, particularly on sexual reproduction, has increased greatly during last two decades. However, studies on the success of transplantation by means of sexual reproduction are still in the initial stage. Several reports have stated that naturally or artificially occurring fragments reduce fecundity or stop gonad development, but those studies were performed only once or just a few times after fragmentation⁶⁷; detailed study on this regard is negligible.

In the Okinawa Churami aquarium, successful reproduction of the transplanted fragments undergoing mass spawning has been reported⁸ which is the first documented work. Okubo et al. (2007)⁹
reported that, some of the cultured colonies suddenly died after a mass spawning event. However, they have not studied the *insitu* success of reproduction. Detailed reproductive data on the wild cultured corals is very important as they are expected to enhance the live coral cover of any degraded reef.

Reefs in the Gulf of Mannar are formed around the 21 uninhabited islands that lie along the 140 km coastal stretch between Tuticorin and Rameswaram of Tamilnadu, Southeastern India. The coral reefs of Gulf of Mannar particularly the Tuticorin region have been severely damaged by human impacts such as coral mining, destructive and unsustainable fishing practices, industrial and domestic pollution and coastal developmental activities. Coral cover has been reduced greatly and hence data on coral reproduction and recruitment becomes essential for the better management of the degraded reef area. *Acropora* occurs in all tropical oceans, abundantly in Indo-Pacific. At least 85 species or about 23% of nominal species of *Acropora* were originally described from the Indian Ocean. Despite the abundance and diversity of *Acropora* species on tropical reefs sporadic studies have described gametogenic cycles in this genus. Reproductive behaviors of the Acroporan corals of Tuticorin coast of Gulf of Mannar was studied by Raj and Edward (2010). This was the first ever report on coral reproduction in any Indian reef.

Outside of Vaan Island of the Gulf of Mannar in the Tuticorin region, coral restoration through the fragment transplantation has been done during 2004 *insitu* mostly with acroporans. Good survival and growth were recorded in the subsequent years and hence live coral cover increased considerably. The major factor involved in the increase of live coral cover was reported to be natural asexual fragmentation. It was reported that that the restored sites could act as donor sites for restoring nearby new damaged reef area and 5 to 10% fragments could be taken from the restored colonies after 24 months to transplant another degraded reef area. However, there was still uncertainty about the sexual behaviors of the restored colonies. This study was conducted to evaluate the restored colonies by means of reproductive behaviors and a comparison has been made in the reproductive behaviors between the naturally occurring and restored coral colonies through fragment transplantation.

### Materials and Methods

Data on Vaan Island (Fig. 1), in the Tuticorin region of the Gulf of Mannar (Lat 8° 50’ N, Long. 78° 13’ E) has fringing reef type which extends up to a depth of 3 m. The fringing reef along the windward side of the Island protects the Island from direct wave action. It was one of the most devastated Islands by coral mining before its elimination in 2005 due to various conservation initiatives and enforcement. Percentage of live coral cover in this Island is considered as fair. Coral restoration through transplantation has been done in the seaward side of this Island during 2004 (Fig. 2).

![Fig. 1 – Map showing study sites](image1)

Monitoring of *Acropora* species was carried out in Vaan Island during the period between January 2008 and March 2010 from both the natural and restored
acroporan coral colonies. Study protocol involved SCUBA diving or snorkeling. Reproductive state of *Acropora* species was gauged by breaking off a branch below the expected sterile zone and noting the presence or absence of eggs. Mature eggs in *Acropora* are pigmented and large enough to be visible to the naked eye. Available evidence indicates that colonies that contain visible, pigmented eggs are likely to spawn on or shortly after the subsequent full moon; colonies with eggs that are visible but un-pigmented (white) are likely to spawn within 1 to 3 months; and colonies with no visible eggs have either just spawned or are unlikely to spawn for at least three months.

Gametogenic cycle was studied in three species, *A. intermedia*, *A. nobilis* and *A. cytherea* in both natural and transplanted colonies between April 2008 and March 2009 following Wallace (1985); Rinkevich and Loya (1985). Total number of oocytes was recorded, and the maximum length and perpendicular width of up to six randomly selected oocytes were measured on each mesentery using a calibrated eyepiece micrometer and photographed with Motic Digital Microscope with imaging Software (Model no. DMB1-223). Even though gametes were visible under the dissection microscope itself, to get the magnified images of the gametes photos were taken with scanning electron microscope (SEM). Few polyps were dissected and dried with ethyl alcohol for SEM photography and photos were taken with the Model JEOL-JSM 5610 LV Scanning Electron Microscope.

The timing of spawning was monitored by SCUBA diving at night. Frequent dives were made after the sunset every day when matured gametes were seen frequently in the coral colonies. Starting from 1800 hrs, dives were carried out with an interval of 30 minutes to investigate the spawning during these suspected nights. Photographs and videos were taken using underwater digital camera (camera model and make) when the spawning was observed. By setting a funnel form bundle-collecting device (bundle collector) under water and above the coral colony, the egg and sperm bundles were collected. This device was watched every day during the suspected spawning period and this process was carried out until spawning happens.

### Results

The pattern of reproduction in *Acropora* species along the Tuticorin coast was studied by Raj and Edward (2010). It was reported that, there is a single reproductive season in Gulf of Mannar between January and March during the study years between 2006 and 2009. In the Acroporan species of Tuticorin coast, visible but immature gametes are seen from January every year and the percentage of immature gametes increase in the next month (February) followed by coloration and maturity during March and spawning in the same month. Starting from April to December all the coral colonies were empty to the naked eyes.

![Fig. 3 — Mean oocyte diameter in Acropora intermedia](image)

![Fig. 4 — Mean oocyte diameter in Acropora nobilis](image)

![Fig. 5 — Mean oocyte diameter in Acropora cytherea](image)
Studies on the gametogenic cycle in three species, *Acropora intermedia*, *A. nobilis* and *A. cytherea* showed a single annual cycle of gametogenesis. Patterns of oogenesis and spermatogenesis were almost similar between the three species with gametes reaching maturity during March every year. No significant difference was found between the natural and restored corals both in the oogenesis and spermatogenesis. There was not much difference in the general pattern or the timing of oogenesis or spermatogenesis between these three species. Oocytes developed over a period of about 7 months (September to March) in *A. intermedia* and *A. nobilis* of natural and restored sources. In *A. cytherea* oocytes developed over a period of 6 months from October to March. Spermarys developed over a period of 4 months in all the three species from both natural and restored corals. Oocytes and spermatocytes mature synchronously within and between polyps within colonies. All the reproductive products (gametes) were released in a single night from all three species both from natural and restored source in March.

No noticeable deviation was found in the size of the oocytes between natural and restored corals (Figs. 3 to 5). The smallest detectable oocyte in *A. intermedia*, *A. nobilis* and *A. cytherea* had a mean diameter of 51.6, 71.7 and 58.8 µm respectively in the natural coral colonies and in the transplanted colonies it was 52, 68 and 57.6 µm respectively. The smallest oocytes were observed during the beginning of the gametogenic cycles. The mean diameter of oocytes in *A. intermedia*, *A. nobilis* and *A. cytherea* was 355.1, 403.3 and 377.2 µm respectively for the natural fragments and in the case of transplanted fragments it was 355, 399.8 and 368.8 µm respectively. The duration of spermatogenesis was similar in *A. intermedia*, *A. nobilis* and *A. cytherea* from both natural and restored source (Figs. 6 to 8). It occurred with 4 month duration between December and March. The smallest mean diameter of spermarys in *A. intermedia*, *A. nobilis* and *A. cytherea* was 238.0, 355.6 and 307.6 µm respectively in natural corals during December while in the transplanted corals it was 243.0, 350.8 and 304.2 µm respectively. The mean diameter of spermarys in *A. intermedia*, *A. nobilis* and *A. cytherea* was 1297.5, 1384.2 and 1300.8 µm respectively for the natural fragments and in transplanted fragments it was 1278.4, 1372.4 and 1279.6 µm respectively.
A prolonged quiescent period was observed in all examined species from the natural and restored sources. *A. intermedia* and *A. nobilis* had a 5 month quiescent period between April and August and *A. cytherea* had a 6 month quiescent period between April and September. During this quiescent period, no gametes were found in the mesenteries of the three examined species. Like the gametogenic cycle, there was no significant difference found in the fecundity between the natural and transplanted corals (Fig. 9). In this study, *A. nobilis* had the lowest mean fecundity with 13±1.1 and 12.2±0.4 oocytes polyp⁻¹ (mean ± SD) respectively for natural and transplanted fragments. The mean fecundity was highest for the species *A. cytherea* with 20.9±1.2 and 20.4±0.5 oocytes polyp⁻¹ respectively for the natural and transplanted fragments. The mean fecundity in *A. intermedia* was 18.2±2.7 and 18.6±3.4 respectively for natural and transplanted fragments. Matured pigmented oocytes were observed in the field in the fresh samples with naked eye, on average 2-3 weeks prior to spawning, though in some colonies matured oocytes were observed for 4-6 weeks prior to spawning. Oocyte color was generally inconsistent among different colonies within species. All the three examined species *A. intermedia*, *A. nobilis* and *A. cytherea* from both natural and restored source spawned in the same night during March every year¹². The mesenteries were empty in April in all the three species indicating complete release of gametes during March. According to student ‘t’ test analysis between natural and restored corals in oocyte diameter and spermary diameter, the results were not significant (P>0.05) for all the three examined species. Figures 10 and 11 show the gamete photographs under dissection microscope and figures 12 and 13 show the gametes under scanning electron microscope.

Synchronous multi-specific spawning among the Acroporans has been observed in Tuticorin region of the Gulf of Mannar¹². After the completion of annual gametogenic cycle, all the monitored species of *Acropora* expelled their reproductive products in a particular night at a particular time. The very next day after the spawning night, all *Acropora* colonies were seen empty indicating that spawning happened in that single night confirming the synchronous process. Spawning was observed during March in all the study years but the exact date of spawning differed from year to year¹². When the pigmented gametes were observed, bundle collecting device was set above the coral colonies expecting the coral spawning. In 2008, colonies with mature gametes were abundant from late February and hence night dives were made every night since then. Spawning was noticed on 8th March 2008 at 20:50 hrs in *Acropora* corals and it lasted only 15 minutes; Egg and sperm bundles were seen in the mouth of the polyps one hour before the actual spawning. All the monitored species of *Acropora* both from natural and transplanted fragments spawned in that time and the floating gametes were abundantly seen on the water surface. On the next day, 9th of March 2008, night dives were again carried out since remnant gametes were observed in an *A. cytherea* colony. On 9th of March 2008, that particular colony spawned at 21:10 hrs and it lasted 10 minutes. 8th and 9th of March 2008 were first and second days after the new moon. It is to note that the spawning on the second day was observed in only one colony of *A. cytherea* as other colonies completed the spawning on the first day itself.

In 2009, spawning was noticed on 3rd of March in all the monitored *Acropora* species from natural and transplanted fragments which was seven days before full moon. It happened at 20:00 hrs and lasted for 20 minutes. In 2010, spawning happened on March 8th which was seven days before new moon in both natural and transplanted corals. Loads of floating gametes were observed at the water surface after spawning during all the study years. Spawned coral colonies from both natural and restored source were empty in the next day. Figures 14 and 15 show the *insitu* photographs of coral spawning.

**Discussion**

*Acropora* species are taxonomically complex because they are highly polymorphic and morphologically identical species which may or may not align with reproductive or genetic boundaries.²¹⁻²³ Species of *Acropora* dominate the shallow parts of reefs and are involved in most issues relating to the ecology, conservation and management of coral reef environments. *Acropora* is thus an exemplar that is both accessible and relevant. Being in the Indian Ocean, Gulf of Mannar has also been bestowed with abundant *Acropora* species. The study on the reproductive behaviors of *Acropora* species is imperative because of its widespread and fast growing
nature.

Fig. 10 — Gametes of *A. intermedia* under Dissection Microscope

Fig. 11 — Gametes of *A. nobilis* under dissection Microscope

Fig. 12 — Single oocyte of *A. nobilis* under Scanning Electron Microscope

Fig. 13 — Single oocyte of *A. cytherea* under Scanning Electron Microscope

Fig. 14 — Underwater photo of coral spawning (*A. intermedia*)

Fig. 15 — Underwater photo of coral spawning (*A. cytherea*)
Survival of the coral transplants is the prime and utmost step in the success of any coral transplantation activity. Ideally in a successful transplantation project, transplanted corals will survive and grow in a manner similar to that of naturally occurring corals. A coral fragment can escape the high risk of mortality after reaching a certain size. Restored acroporan corals outside Vaan Island had exhibited a high growth above 20 cm in 2 year study period with a mean growth rate of 0.5 to 1.2 cm/month and continued growing well as the natural colonies. Successful reproduction in the transplanted fragments has been reported by Nonaka et al. (2003); Okubo et al. (2007; 2009; 2010); Guest et al. (2002, 2005a, b) support that reproductive synchrony happens even in the equatorial regions despite a negligible variations in the environmental parameters.

Fadalallah (1983) suggested that corals with broadcasting modes of reproduction have synchronous cycles of gametogenesis regardless of their geographic distributions. Single annual gametogenic cycles have been reported in many broadcast-spawning species. In most of these corals, gamete development occurs for less than twelve months each year, and culminates in a short spawning period during spring or summer. The 3 Acropora species examined in this study were broadcast spawners. It also revealed that there was a single annual cycle of gametogenesis in the Gulf of Mannar in the species A. intermedia, A. nobilis and A. cytherea of natural and transplanted colonies and a significant synchrony was observed among the three examined species and the gametogenic cycle was exactly alike between natural and transplanted colonies. Smith and Hughes (1999) reported that the fecundity of artificially fragmented Acropora colonies was lower than that of the intact colonies of similar size. But to the contrary, in this study, no significant variation was found between natural and transplanted fragments in terms of fecundity. Overall, the fecundity was much higher than several other areas (e.g. Wallace, 1985 (GBR); Kenyon, 1992 (Hawaii); Shimoike et al., 1992 (Okinawa); Wilson, 1998 (Solitary islands)).

The spawning pattern observed in Vaan Island showed synchrony among Acropora species and supported by the studies from Japan, Taiwan, Palau and Singapore, where more synchronized multispecific spawning of Acropora assemblages was observed. Oliver et al. (1988) compared reproductive data from five sites extending from Heron Island reef on the southern GBR (23.5°S) to Madang on the north coast of Papua New Guinea (PNG) (5°S), and found a progressive breakdown in spawning synchrony north of the latitude 14°S. However, Guest et al., (2005b) argued that no coastal environment was truly non seasonal, and therefore reproductive seasonality and some degree of multispecific spawning may occur on equatorial reefs. Likewise, in Vaan Island, spawning synchrony was
observed among the _Acropora_ species despite being in the equatorial region where not much environmental fluctuation is experienced. Spawning in Gulf of Mannar was noticed during March in every year and this time of the year is related with coral spawning in many parts of the Indian Ocean. Spawning slicks were observed in March 1997 on Ari Atoll in the Maldives. Mangubhai, (2007)\textsuperscript{43} observed that the peak spawning period for _Acropora_ species in Kenya was between January and April. Multispecific synchronous coral spawning was documented by Guest _et al._ (2002)\textsuperscript{16} in Singapore during 2002 after the March full moon. Vicentuan, et al., (2007)\textsuperscript{45} recorded seasonal peak in coral reproduction from March to May in Philippines. Spawning was observed in the transplanted colonies in that very time when the natural colonies did; which provides comprehensive evidence that transplanted colonies also actively participate in the coral reproduction as the natural colonies do. 

Seasonal changes in sea water temperature are frequently cited as an important environmental factor controlling gametogenic cycles or planula-release periods in scleractinian corals. The spawning patterns for _Acropora_ in different regions have been related either with temperatures rise\textsuperscript{17,46-49} or summer maximum\textsuperscript{50}. In Gulf of Mannar, the sea surface temperature variation ranges from 5 to 6\textdegree C throughout the year. The lowest temperatures are recorded during December (around 27\textdegree C) and the highest temperatures are recorded during May (around 33\textdegree C). During March, there is a sharp elevation in the sea surface temperature (2 to 3\textdegree C) which forces the mature corals to release their gametes. Lunar periodicity has been found in a wide range of corals around the world. But on the contrary, no obvious pattern in the coral spawning has been observed in the present study relating with lunar periodicity since spawning in three consecutive years happened irrelevant to the full moon or new moon.

Fragmentation and removal of parts of the colony may reduce the reproductive ability of corals\textsuperscript{51-53}. It is expected that the reduction in colony size due to fragmentation may affect reproductive output\textsuperscript{54}. Connell (1973)\textsuperscript{25} postulated that whether a colony joins sexual reproduction or not is determined by size of colony or age of polyps in the colony and was supported by Okubo et al. (2007)\textsuperscript{9}. Kojis and Quinn (1985)\textsuperscript{51} described in their study on _Goniastrea favulus_ that the age of polyps might affect sexual reproduction. Since the transplanted colonies in this present study are relatively large and polyps are reasonably old, they are matured enough to be reproductively active. As the global degradation of coral reefs because of human induced disturbances coupled with natural factors is increasing, the successful restoration practices become the need of the hour. This study provides a bench mark restoration activity by fragment transplantation outside Vaan Island of the Gulf of Mannar. After the transplantation in 2004, the live coral cover of this Island has increased steadily providing hope to the reef managers and researchers.

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