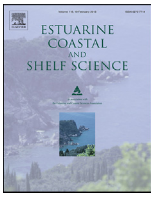
Estuarine, Coastal and Shelf Science 128 (2013) 41–51

Contents lists available at SciVerse ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss



A first endeavour in restoring denuded, post-bleached reefs in Tanzania

Nsajigwa E. Mbije [a,b,c,*], Ehud Spanier [b], Baruch Rinkevich [c]

[a] *Sokoine University of Agriculture, Faculty of Forestry and Nature Conservation, Wildlife Management Department, P.O. Box 3073, Morogoro, Tanzania*
[b] *The Leon Recanati Institute for Maritime Studies and Department of Maritime Civilizations, University of Haifa, Mount Carmel, Haifa 31905, Israel*
[c] *Israel Oceanographic and Limnological Research, National Institute of Oceanography, Tel-Shikmona, P.O. Box 8030, Haifa 31080, Israel*

ARTICLE INFO

Article history:
Received 3 July 2012
Accepted 29 April 2013
Available online 16 May 2013

Keywords:
coral bleaching
coral gardening
Mafia
restoration
Zanzibar

ABSTRACT

The worldwide decline in coral reefs has prompted a search for effective restoration protocols. We transplanted 6912 and 7110 corals (*Acropora muricata*, *Acropora nasuta*, *Acropora hemprichi*, *Pocillopora verrucosa*, *Porites cylindrica*, *Millepora* sp.) in Changuu, Zanzibar and Kitutia, Mafia, Tanzanian reefs that suffered in 1998 from a massive coral bleaching incident, causing a wide spread coral death. No sign for natural recovery has been recorded thereafter. In each site, we randomly set up 12 plots (36 m^2 each), of which three were transplanted with a mix of three *Acropora* spp. (Treatment 1, T1), three with a mix of all six scleractinian species (T2), and six served as controls. Within one month of transplantation, an outbreak of *Acanthaster planci* in Changuu caused mortality at 50%. One year survival of transplants in T1 and T2 at Kitutia reached 66.4% and 62.5% respectively, significantly higher than at Changuu; an outcome recorded through species-by-species comparisons on four species only (*P. verrucosa, P. cylindrica, A. muricata, A. nasuta)*. After one year no significant difference was documented in ecological volumes (EV) between T1 and T2 in stark contrast to the among species comparisons in T1, at each site. A within treatment one-way ANOSIM comparison for fish assemblage structures performed between the first and last three months of the transplantation year (Kitutia reef) revealed strong separation (T1, Global $R = 0.743$, $P < 0.001$; T2, $R = 0.445$, $P < 0.001$ and T3, $R = 0.694$, $P < 0.001$) while the same treatment revealed weak separation at Changuu site T1 ($R = 0.035$, $P > 0.262$) and T2 plots ($R = 0.119$, $P < 0.043$). Similarly, one-way ANOSIM done on the initial and last 3-month periods on invertebrates' community composition (at all sites, except T1 of Changuu reef), showed no significant difference between community composition at both ends of the sampling period. Altogether, transplantation cost (US$0.19/colony) suggested that large scale transplantation is economically viable. Cumulatively, field results and economic evaluations showed that transplantation of nursery-grown colonies might uphold critical ecosystem functions while used in reversing phase shift states in coral reefs.

1. Introduction

Coral reefs worldwide are facing continued decline due to a variety of natural and anthropogenic instigations (Hoegh-Guldberg, 2004; Edwards and Gomez, 2007). While in the past, coral reefs managed to recover from perturbations in a short time (Edwards and Gomez, 2007; Dudgeon et al., 2010) through coral fragmentation (Lewis, 1991) or larval recruitment (Nzali et al., 1998), worldwide reef recovery trends and processes have recently becomes lower because of substrate instability (Wells and Alcala, 1987) or larval depletion (Quinn and Kojis, 2006), altogether reducing ecosystem resilience; leading to ecological phase shifts in which coral reefs become algal-dominated systems (Hughes et al., 2007). Responding to reef ecosystems' decline, several approaches made suggestions for novel applications in order to rehabilitate reef services (Franklin et al., 1998; Lesica and Allendorf, 1999; Lindahl, 2000; Köhlin and Ostwald, 2001; Bruckner and Bruckner, 2001; Bowden-Kerby, 2001; Ortiz-Prosper et al., 2001; Bongiorni et al., 2011; Guest et al., 2011; Horoszowski-Friedman et al., 2011; Linden and Rinkevich, 2011; Muko and Iwasa, 2011). The declaration by the Convention on Biological Diversity that restoration of terrestrial, inland water and marine ecosystems is inevitable in order to restore ecosystem functioning and ecosystem services (Normile, 2010) is a strong evidence of global support in ecological restoration efforts. Accordingly, there have been many localized attempts in various parts of the world to design appropriate active restoration protocols especially in denuded reef areas. One such

---

* Corresponding author. Sokoine University of Agriculture, Faculty of Forestry and Nature Conservation, Wildlife Management Department, P.O. Box 3073, Morogoro, Tanzania.
E-mail addresses: mbije@yahoo.com, nmbije@gmail.com (N.E. Mbije).

0272-7714/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecss.2013.04.021

attempt is the 'reef gardening' tenet (Rinkevich, 2005, 2006, 2008), a two steps restoration operation which has been tested in various reefs worldwide (Bowden-Kerby, 1997; Amar and Rinkevich, 2007; Shafir and Rinkevich, 2008, 2010; Putchim et al., 2009; Levi et al., 2010; Mbije et al., 2010; Shaish et al., 2010a, b; Bongiorni et al., 2011; Linden and Rinkevich, 2011). This tenet incorporates stock farming of small coral fragments in mid-water floating nurseries which, upon reaching suitable sizes, are transplanted onto denuded reef areas. A major conclusion emerged from the above studies is that the application of appropriate active restoration protocols may enhance reef recovery (Rinkevich, 2005, 2006, 2008). This is supported by experimental manipulations showing that improved live corals coverage and their structural complexity influence significantly the recovery of reef fish communities (Garpe and Ohman, 2007; Cabaitan et al., 2008; Ferse, 2009). Coral gardening studies (Lindahl, 2003; Soong and Chen, 2003; Rinkevich, 2005, 2006, 2008; Amar and Rinkevich, 2007; Shafir and Rinkevich, 2008, 2010; Shaish et al., 2008, 2010a,b; Chou et al., 2009; Putchim et al., 2009; Omori and Iwao, 2009; Edwards, 2010; Ferse, 2010; Iwao et al., 2010; Levi et al., 2010; Lirman et al., 2010; Mbije et al., 2010; Bongiorni et al., 2011; Guest et al., 2011; Horoszowski-Friedman et al., 2011; Linden and Rinkevich, 2011; Muko and Iwasa, 2011) provided results showing that coral reef restoration can be applied successfully and efficiently at very low costs.

Like in other countries (Baticados, 2004; Wells, 2009), a significant reef area in Tanzania faced an advanced degradation state due to decades of intermittent anthropogenic disturbances, destructive fishing and current proliferation of touristic activities in Mafia Island, Zanzibar and Pangani beaches (Wagner, 2005). Although most of anthropogenic impacts have relatively been controlled, much of the reef system in Tanzania has remained severely damaged in the last 15 years ensuing the1997/1998 El-Niño that caused a massive coral bleaching incident, followed by a wide spread coral death (Lindahl et al., 2001; Mbije et al., 2010), with no signs for natural recovery. The combined effects of anthropogenic activities and the 1998 coral-bleaching incident are therefore accountable for the continued pressure and demise of the large shallow water reefs in Tanzania (Lindahl et al., 2001). Such a grave situation requires the intervention of scaled-up management and the application of appropriate active restoration protocols (Rinkevich, 2005, 2006, 2008; Mbije et al., 2010).

In response to the persistent decline of the coral reefs in East Africa, an experimental study based on the 'gardening concept' was done in two Tanzania sites, Changuu reef in Zanzibar and Kitutia reef in Mafia (Mbije et al., 2010). We (Mbije et al., 2010) already documented that the coral gardening approach could be used in Tanzania to generate large quantities of coral colonies for restoration of damaged reefs at relatively low cost. Following that, the major aim of this study was to test the applicability and efficiency of the second step of the 'gardening tenet', the successful transplanting of nursery reared coral colonies. This was performed by monitoring transplants' survival/bleaching, colonial ecological volumes, coral recruitment and transplantation impacts on reef fish and community structures of reef dwelling invertebrates. The underlying principle used in this study is based on the understanding that reefs' biological and physical features influence structures of reef communities (Cabaitan et al., 2008). Furthermore, in order to assess the economic applicability of our approach, we also analysed overall costs associated with transplantation.

2. Material and methods

2.1. Study location

The study was carried out in Changuu reef of Unguja Island in Zanzibar (6°16′ N 39°18′ E) and Kitutia reef in Mafia Island Marine Park (7°40′ N, 4°40′ E), about 120 km apart (Fig. 1a, b, c). Changuu Island has a shallow fringing reef on the northern side (3–10 m at high spring tide) and a shallow south side dominated by sea grass mats. The dominant coral genus in Tanzanian reefs is *Acropora* (Richmond, 2002), which is evident in the extensive mass of dead *Acropora* branches, especially at Kitutia reef, that accumulated after the unprecedented 1997/1998 mass bleaching followed by extensive mortality (Lindahl et al., 2001). Similarly, dead coral fragments of mixed species dominate Changuu reef (Mbije, personal observation). The devastated areas in the two reefs have shown no signs of recovery in the last 13 years, with dead coral fragments overgrown by extensive algal mats.

2.2. Coral transplantation

We used one-year old nursery reared scleractinian colonies from six species: *Acropora muricata*, *Acropora nasuta*, *Acropora hemprichi*, *Pocillopora verrucosa*, *Porites cylindrica* and *Millepora* sp. (Mbije et al., 2010). The transplantation sites at Changuu and Kitutia (about 15 and 23 km respectively from nurseries) were located at the same depths as the original site from which the nursery materials originated and consisted of substrates with consolidated dead coral fragments, loose gravel and a few live corals. Farmed colonies were carefully removed from the nursery by means of carpentry scissors, their bases cleaned from settling sedentary organisms, immersed in marked, large water-filled plastic bins, and loaded onto a boat, before being transferred to the transplantation sites. At each transplantation site, we haphazardly established 12 plots (each 36 m^2) that were clearly marked for further inspection; six of which were transplanted with nursery reared coral colonies. We followed a pre-set design comprised of three treatments (T1-T3): three plots were transplanted with a mix of three *Acropora* spp. (T1), three plots transplanted with a mix of all six coral species (T2) (Appendix A) and six plots, designated within non-transplanted areas, served as controls (T3). Each transplanted plot was further partitioned into nine sub-plots, each 4 m^2 (Fig. 2a). Eight sub-plots within each plot were transplanted with coral colonies (some were populated with colonies of the same coral genotype, with various genotypes of the same species, or different coral species) at 16 cm distance from each other, while the central 4 m^2 sub-plot was left unattached, to elucidate possible impacts of surrounding transplanted plots (Fig. 2a). Each 4 m^2 sub-plot was populated with 144 coral colonies, 1152 colonies per a 36 m^2 plot (Fig. 2a–c). In total, 6912 coral colonies were out planted in Changuu reef at Zanzibar and 7110 in Kitutia reef at Mafia. Although the design and fragment spacing was the same in both sites, we transplanted extra colonies in Kitutia reef and these were not part of the monitored plots.

A large proportion of the substratum at Kitutia reef is composed of consolidated dead coral branches, mostly of *Acropora* spp., while at Changuu reef the substratum is composed of hard rock with attached dead coral branches. Two transplant attachment techniques were tested, (a) plugging the short pieces of the hosepipes carrying corals directly between the firmed attached dead coral branches (4123 and 5324 transplants in Changuu and Kitutia respectively, and (b) plugging the short pieces of hosepipes into holes drilled in the substrates (2789 and 1786 transplants in Changuu and Kitutia respectively). General-purpose epoxy compound (M-seal®) reinforced the attachment of loose transplants to the substratum.

2.3. Monitoring and data analysis

Once a year, a team of three divers monitored the transplantation plots and transplants for bleached colonies, detached transplants, survival rates, corals' size measurements, fish surveys,

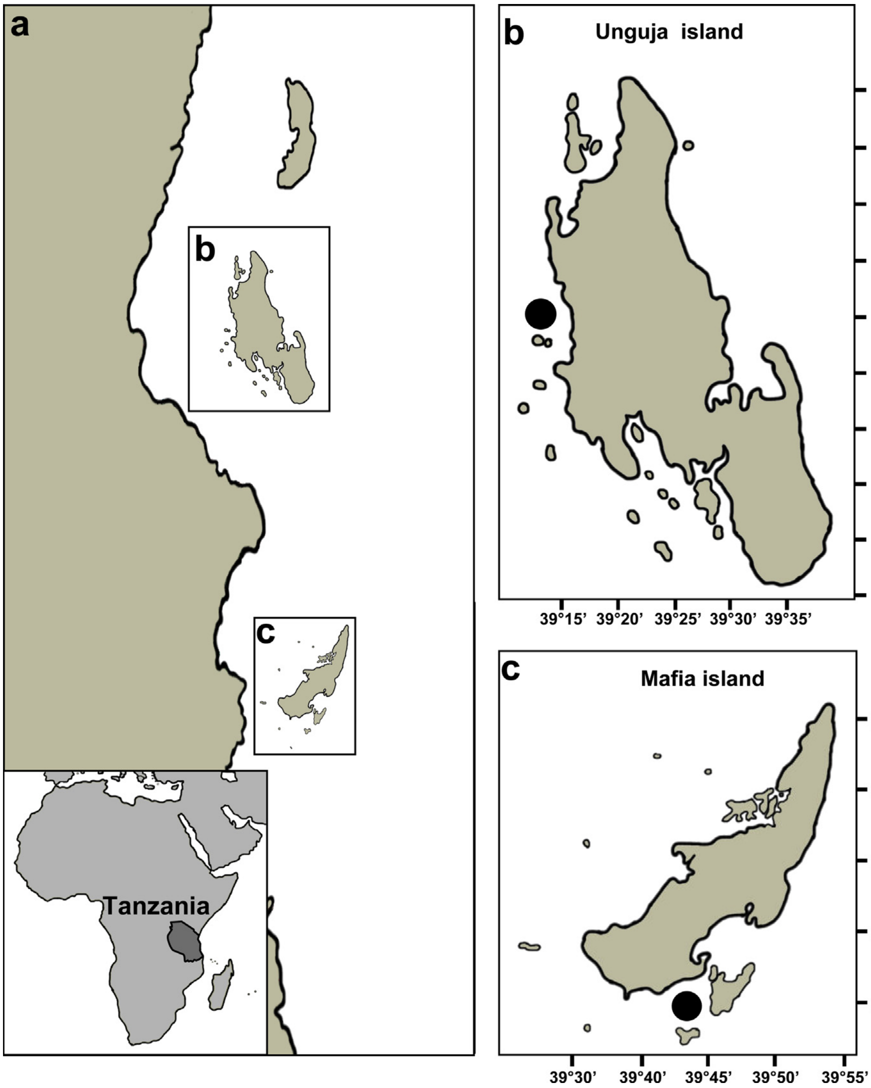


Fig. 1. Map of Tanzanian coast (a) and Tanzania (Africa insert), showing (b) Changuu and (c) Kitutia transplantation sites in Zanzibar and Mafia Islands, respectively.

and recruitment of selected reef associated invertebrates. Every three months, we assessed size-measurements of transplants in the field by measuring height, width and length of each colony with plastic callipers. From these measurements, the colonies' ecological volumes (EV) in cm^3 were calculated as $\text{EV} = \pi^*\text{H}^*([W + L]/4)$ (Rinkevich and Loya, 1983).

Fish surveys involved identifying and counting all adult individuals found to occupy each 3D setting (plot and water column around and above the fragments); all fishes > 3 cm long were identified to the lowest taxon possible. Censuses were performed by slow-motion scuba diving that allowed counting fish populations without disturbing the animals. This exercise was repeated in each plot of the three treatments and fish censuses were conducted between 1000 H and 1500 H and completed within the same week (the exercise was repeated twice for each plot). Values for fish abundance, species richness and species composition were analysed. While fish abundance refers to the number of fish of a certain species, species richness is the total number of fish species, and species composition refers to the relative abundance of fish species per treatment/plot. Censuses of large invertebrates were carried out under the same protocol, with a single deviation, observing their presence within crevices, in the substrates, between coral branches, underneath coral colonies and on hard substrate. Invertebrate abundance and species richness were used in the analysis.

2.4. Coral recruitment

From the start of the transplantation experiment, we closely monitored the central bare sub-plots within the plots for coral settlement. Because of the lengthy underwater time required for this procedure, we were forced to conduct our monitoring at low spring tide (mean spring tide at 3.3 m and maximum at 4.0 m). We applied an extensive underwater search procedure that included fanning away sediments while searching for recruits. Since most coral recruits are very small at settlement and their growth rate is slow (Wallace and Bull, 1981), we concentrated on established recruits of size ranging between 0.5 and 2.0 cm. This was also performed in order to minimise confusion or mistakes in coral species identification. Identification of coral recruits to the lowest possible taxon was done with the aid of the key plates found in English and Wilkinson (1994) and Babcock et al. (2003) that were laminated to

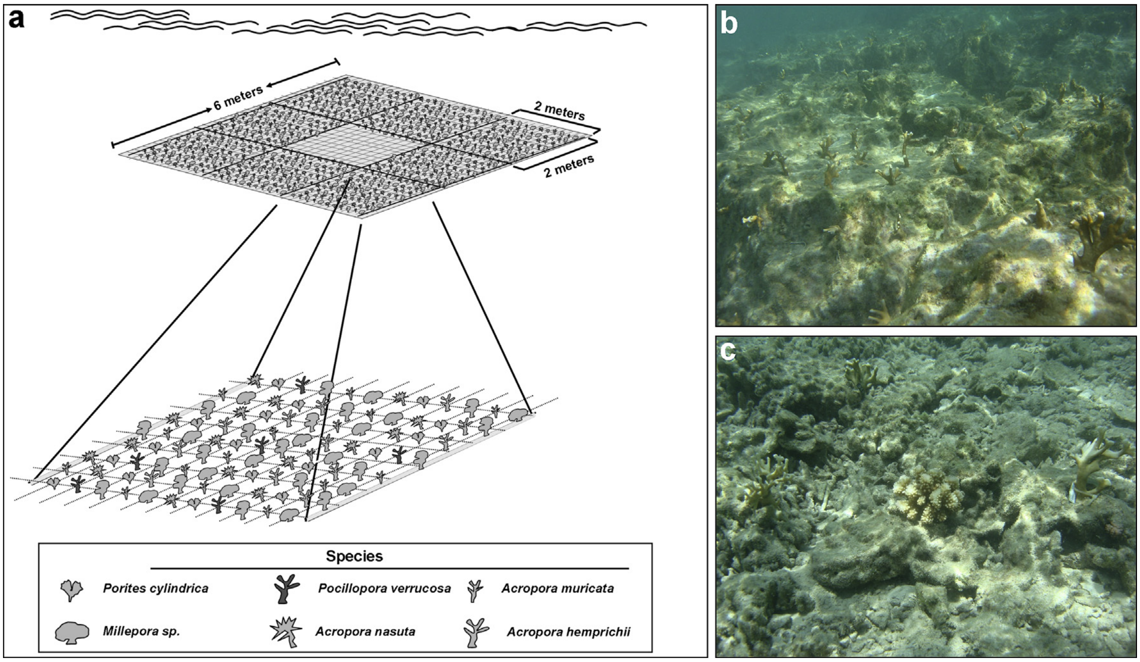


Fig. 2. Coral transplantation. (a) A scheme of 36 m^2 transplantation plots with eight 4 m^2 sub-plots containing coral transplants and one 4 m^2 bare sub-plot at the middle for the *Acropora* and mixed species plots. The enlarged mixed species plot shows corals spaced at 16 cm from each other, (b) coral transplants *in situ*, immediately after transplantation; *Millepora* sp., 4 m depth at Changuu reef and (c) three months after transplantation; *Millepora* sp. and *Pocillopora verrucosa,* 4 m depth at Kitutia reef.

suit underwater work. Results were summarised as average numbers per species/treatment/site.

Average colonies' sizes, mean percentages of survival, detachment and bleaching were calculated for each sub-plot/treatment/monitoring date. Results were analysed by using an SPSS 16 2007 data editor. We employed *t*-test when comparing between sites and one way-ANOVA for comparison between treatments. Prior to the analysis, all data were subjected to Levene's (1960) test to check for assumption of homogeneity of variances and whenever necessary, the data were square root transformed. Similarly, the analysis in fish and invertebrate assemblage structure within each treatment, among treatment and between sites, were analysed using either one way or two way crossed ANOSIM (on density data) based on Bray–Curtis similarity measures (Clarke, 1993). To reduce the weight of dominant values (mostly from schooling taxa), the data were square root transformed. Non-metric multidimensional scaling (nMDS) ordinations were used to visualise the patterns of similarities among sites.

3. Results

3.1. Economic evaluation of coral transplantation

We out planted 14, 022 coral colonies in both sites as follows: *Acropora muricata* 3464, *Acropora hemprichi* 2879, *Acropora nasuta* 2087, *Pocillopora verrucosa* 2095, *Millepora* sp. 2090 and *Porites cylindrica* 1780. In each dive, the time taken to fix transplants in rubble was longer than in drilled holes, though the latter consumed more diving tanks. Taking these two facts into account, the actual costs for each type of attachment was similar, US$0.14 per colony or US$2020 for all 14,022 coral colonies (Table 1), which is a minimal number compared to the benefits derived from transplantation in terms of ecological functions and tourism amenities transplants provide. In addition, such low costs can also be applied even in developing countries where resources are scarce.

3.2. Coral detachment, survival and bleaching

Most transplants remained firmly attached to the substrates in the first month post transplantation, with only few detachments recorded in the dead coral fragment mixed species plots. These include 199 (4.8%) colonies in Changuu and 247 (4.6%) in Kitutia. Detached colonies were reattached to their original places by underwater epoxy. However, one month post transplantation, an unexpected outbreak of the crown-of-thorns starfish, *Acanthaster planci*, was documented at Changuu site in T1 and T2 but not in T3 (control plots), or in adjacent natural reef areas. Almost half of the Changuu transplants were lost to predation (Fig. 3a). No single *Acanthaster* specimen was seen during a preliminary survey carried out on the entire reef when the decision on transplantation sites was made. In total, more than 180 *Acanthaster* specimens were handpicked, with up to 30 individuals per plot (with the aid of volunteer fishermen) and buried on the beach. Following this predation, almost no further mortality was observed in the next 10 months (one-year survival of 52 and 51% in T1 and T2 plots respectively (Fig. 3a). At Kitutia reef, Mafia, about 25% of initial coral fragments were removed through the activities of fishermen. One year survival reached 66.4% and 62.5%

Table 1
Detailed cost for 14,022 coral colonies transplantation in Tanzania (1 US$ to 1300 Tanzanian Shillings).

Item	Quantity	US$
Hiring a boat	80 US$ per day × 12 days	960
Paying volunteer divers	3 divers @ 10 US$ × 12 days	360
Epoxy compounds (M-seal®)	100 × 5 US$	500
Miscellaneous	Small tools (knives, cutters, brushes, etc.)	200
Total		2020

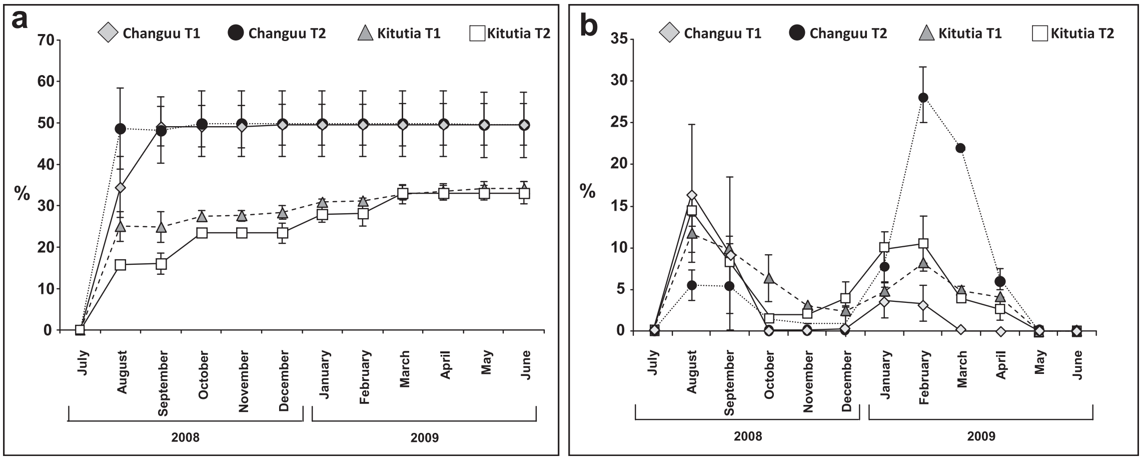


Fig. 3. One year outcomes for transplants in treatments 1 and 2 at Changuu in Zanzibar and Kitutia in Mafia. (a) Accumulated mean mortalities; (b) Mean bleaching levels. Error bar represent ± standard error.

in T1 and T2 respectively, significantly higher than in Changuu ($p < 0.05$; *t* test). Species-by-species comparisons revealed lower survival of *Pocillopora verrucosa, Porites cylindrica*, *Acropora muricata* and *Acropora nasuta*, in the Changuu site as compared to Mafia ($p < 0.05$; *t*-test). *Acropora hemprichi* and *Millepora* sp. showed no significant differences in survival between the two sites ($p > 0.05$; *t* test).

In both sites, high levels of bleaching events were recorded one-month post transplantation (Fig. 3b). At Changuu, T1 and T2 plots showed 16% and 22% bleaching respectively. No significant difference in bleaching was recorded between plots that were transplanted with *Acropora* species (T1; $p > 0.05$; one-way ANOVA) but bleaching differed significantly between T2 plots that were transplanted with mixed species ($p < 0.05$; one-way ANOVA). In Kitutia reef, bleaching was 11% and 16% for T1 and T2, respectively (Fig. 3 b). No significant difference in bleaching was recorded between *Acropora* species plot in T1 and between mixed species plot in T2 ($p > 0.05$; one-way ANOVA). In both sites, the most resilient species were *Millepora* sp. and *Acropora hemprichi*, with only 76 (0.54%) and 67 (0.48%) bleached colonies, respectively, while *Acropora muricata* ($n = 302$, 23.6%), *Pocillopora verrucosa* ($n = 211$, 32.1%), *Porites cylindrica* ($n = 192$, 37.2%) and *Acropora nasuta* ($n = 188$, 18.5%) suffered from higher bleaching than the other species (n = number of bleached fragments). Among the severely bleached coral species were those transplanted by plugging directly between the dead coral fragments. These include *Acropora muricata* ($n = 65$, 20%), *P. verrucosa* ($N = 72$, 34%), *Porites cylindrica* ($n = 79$, 41%), and *A. Nasuta* ($N = 103$, 55%). Bleaching did not result in significant transplants' mortality as 95% of bleached colonies recovered within two months after transplantation.

A second bleaching event occurred from February to April 2009 (Fig. 3b), when for several weeks, water temperatures rose to 32.1 °C and 31.8 °C in Changuu and Kitutia respectively, causing wide spread bleaching in many reefs of Tanzania (http://www.cordioea.org/bleachingalert, 2009). On average, at Changuu site we counted seven (0.7%) bleached *Galaxea fascicularis* colonies/plot (including the six control sub-plots), 19 or 0.78% *Pocillopora verrucosa*, 21 or 2.8% *Porites cylindrica* and five *Fungia* sp., while at Kitutia reef only two bleached coral species were recorded, *Acropora muricata* ($n = 31$, 6.2% and *P. verrucosa* ($n = 11$, 7.2%) in the three mixed plots. Bleaching was 100% in *Galaxea fascicularis* and *P. verrucosa* colonies with *Porites cylindrica* colonies turned pale for one month.

3.3. Transplants growth rates

We closely followed the growth of the same 180 representative and marked coral colonies per treatment, once a month (i.e., 360 per site for both attachment protocols). The data for each treatment in each site were analysed separately for comparison purposes. It was found that while the colonial ecological volumes (EV) increased slightly after 90 and 120 days, EV nearly tripled after 180 days and quadrupled after 270 days (Fig. 4). In Changuu reef, *Acropora nasuta* EV in plots T1 and T2 increased 12 and 17 fold by day 360 respectively. *A. Muricata* EV increased 6 and 7 times in T1 and T2 respectively, and *A. Hemprichi* increased 6 and 4 times, respectively (Fig. 4a). *Pocillopora verrucosa* and *Porites cylindrica* EV increased seven and five times in T1 and T2, respectively, and *Millepora* sp. EV increased only four times in the first year after transplantation (Fig. 4a). A significant difference in EV increase was recorded between transplanted *A. nasuta, Acropora muricata* and *Acropora hemprichi* within T1 ($p < 0.05$; one-way ANOVA). However, among *Acropora* species, in the same period, no significant difference was observed between T 1 and T2 plots ($p > 0.05$; one-way ANOVA).

Similar patterns of EV increase were recorded at Kitutia reef in Mafia (Fig. 4b). The EV values in the first three and six months increased slightly but tripled after 270 days in all species and increased ten times after 360 days. After 360 days, EV of *A. Nasuta* increased 11 times in T1 and T2 plots. The EV values for *Acropora muricata* increased three and seven times after 270 days and six and twelve times after 360 days in T1 and T2 plots, respectively. Similarly, the EV in *Acropora hemprichi* increased three and two times after 270 days and five and six times after 360 in T1 and T2 plots, respectively. We recorded 4 fold EV increase in *Pocillopora verrucosa* and 3 fold increase in *Millepora* sp. after 360 days in T2 where as *P. Cylindrica* EV multiplied 12 times after 360 days. In Kitutia reef, a significant difference in EV increase was observed between *A. muricata*, *Acropora nasuta* and *A. Hemprichi* in T1 ($p < 0.05$; one-way ANOVA). EV increase comparisons for T1 and T2 plots revealed no significant difference for the above three coral species ($p > 0.05$; one-way ANOVA).

3.4. Impacts of transplantation on fish communities

Throughout the experimental duration, a total of seven species were observed at Changuu reef and 29 fish species at Kitutia reef,

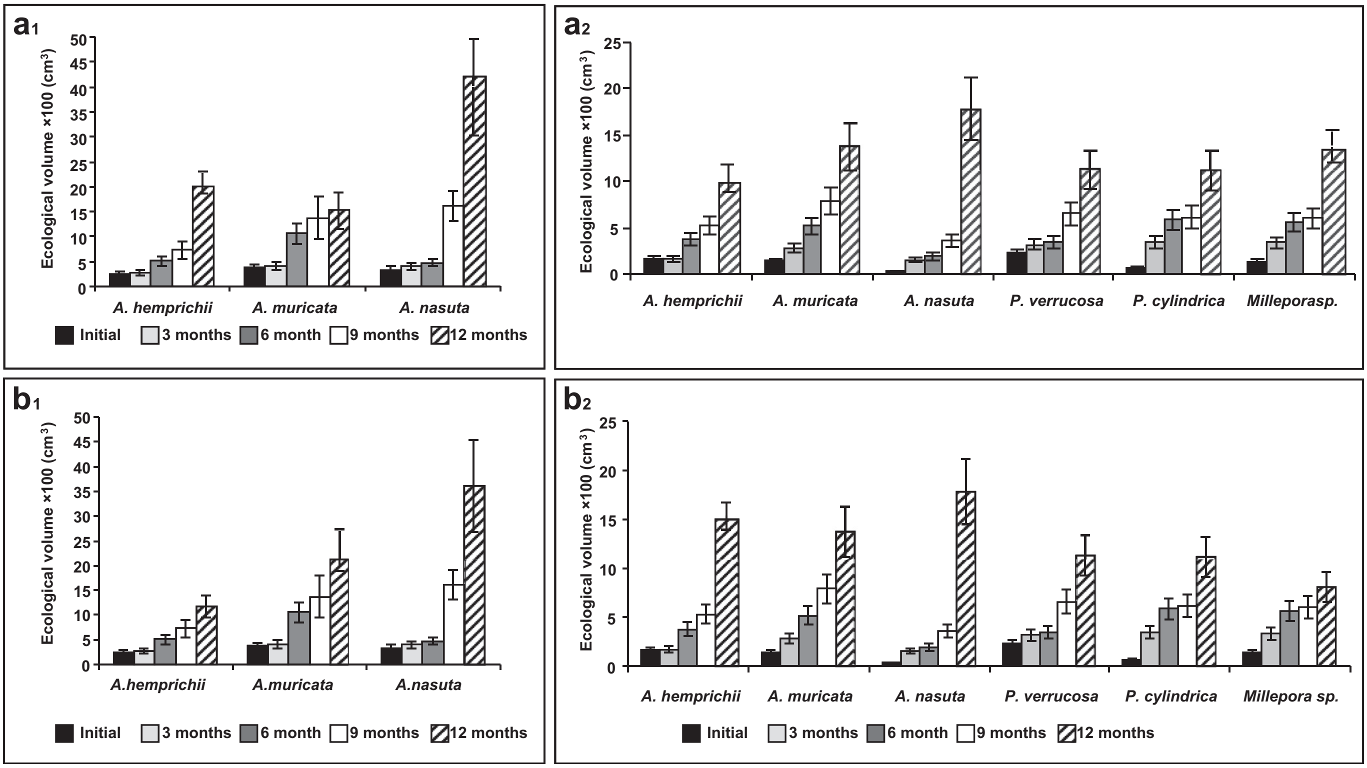


Fig. 4. Mean (±SE) ecological volumes for transplanted coral species; (a) Changuu and (b) Kitutia reefs. 1–2 refer toT1 and T2, respectively.

appearing in all three treatments/sites (Appendix B). A within treatment one-way ANOSIM comparison for fish assemblage structures performed between the first and last three months of the transplantation year (Kitutia reef) revealed a strong separation (T1, Global $R = 0.743$, $P < 0.001$; T2, $R = 0.445$, $P < 0.001$ and T3, $R = 0.694$, $P < 0.001$). At Changuu site, a within treatment one-way ANOSIM comparison of fish assemblage structures between the first and last three months of the experiment, revealed no difference in the T1 plots, and a very weak one in the T2 treatment while T3 showed no significant difference ($R = 0.035$, $P > 0.262$, $R = 0.119$, $P < 0.043$, $R = -0.052$, $P > 0.750$ respectively). These patterns are illustrated in the nMDS ordination plots (Fig. 5).

3.5. *Invertebrate composition and abundance*

In both sites, Echinoidea and Asteroidea were the two major invertebrate groups observed in T1, T2 and T3 plots with some individuals from one species of class Gastropoda (Appendix C). A within treatment one-way ANOSIM comparison of invertebrates assemblage structures between the first and last three months of the transplantation year at Kitutia reef revealed weak separations for T1 plots ($R = 0.014$, $P > 0.322$) and weaker for T2 ($R = -0.067$, $P > 0.881$) and T3 ($R = -0.026$, $P > 0.552$). In contrast, at Changuu reef, the difference between community compositions in T1 between the first and last three months of the transplantation appeared strong, while it was less in T2 and T3 ($R = 0.55$, $P < 0.001$,$R = 0.104$, $P > 0.10$ and $R = 0.426$, $P > 0.001$ respectively). These patterns are illustrated in the nMDS ordination plots (Fig. 6).

3.6. *Effects of transplantation on central empty blocks*

During the first two months after transplantation, no coral recruitment was recorded in all 12 central T1, T2, and T3 bare sub-plots in both sites. However, as from the third month there was a continuous recruitment of corals in T1 and T2 central empty sub-plot, less recruitment in Kitutia empty T3 sub-plot, and no recruitment in Changuu empty T3 sub-plot (Fig. 7a, b; therefore, no sub-Fig. 7a 3 is provided).

Three species of *Acropora* (*Acropora hemprichi*, *A. Nasuta* and *Acropora muricata*) dominated coral recruitment in Changuu T1 central sub-plot after 12 months (Fig. 7a). *Acropora hemprichi*, *A. muricata* and *A. Nasuta* reached densities of 1.4, 1.25 and 1.2 recruits/m^2, respectively, showing no significant difference ($p > 0.05$; one-way ANOVA). We recorded recruits belonging to the other species transplanted (*Millepora* sp. 0.4/m^2; *Pocillopora verrucosa*0.4 m/m^2, and *Porites cylindrica*, 0.2/m^2) and of species that were not part of this experiment (*Pocillopora damicornis*, 0.88/m^2, *Galaxea fascicularis*, 0.75/m^2 and *Porites rus*, 1.0/m^2). In T2, the most common recruited species in the bare sub-plot was *Millepora* sp. (1.6 individuals/m^2; Fig. 7b), followed by *Acropora muricata* (1.25/m^2), *Acropora nasuta* (1.1/m^2), *Acropora hemprichi* and *Pocillopora verrucosa* (each 1.0/m2). Comparison of recruits' densities between the three *Acropora* species in T1 and T2 showed no significant difference ($p > 0.05$; one way ANOVA).

Acropora species were the most common recruits in Kitutia central sub-plot. In T1, *Acropora muric*ata showed the highest figure (2.0 individuals/m^2) followed by *Acropora hemprichi* (1.75/m^2), *Acropora nasuta* and *Pocillopora verrucosa* (each 1.50/m^2), and *Millepora* sp. (0.75/m^2), with no significant difference in densities among them ($p > 0.05$; one-way ANOVA). There was no record for *Porites cylindrica* recruits in this treatment. In T2, *Acropora nasuta* was the most common (2.0 individuals/m^2) followed by *Acropora muricata* (1.75/m^2), *Acropora hemprichi* and *Millepora* sp. (each, 1.5/m^2), *P. verrucosa* (1.0/m^2) and *Porites cylindrica* (0.25/m^2), showing no significant difference among them ($p > 0.05$; one way ANOVA). At this site, we recorded lower level of hard corals recruitment in

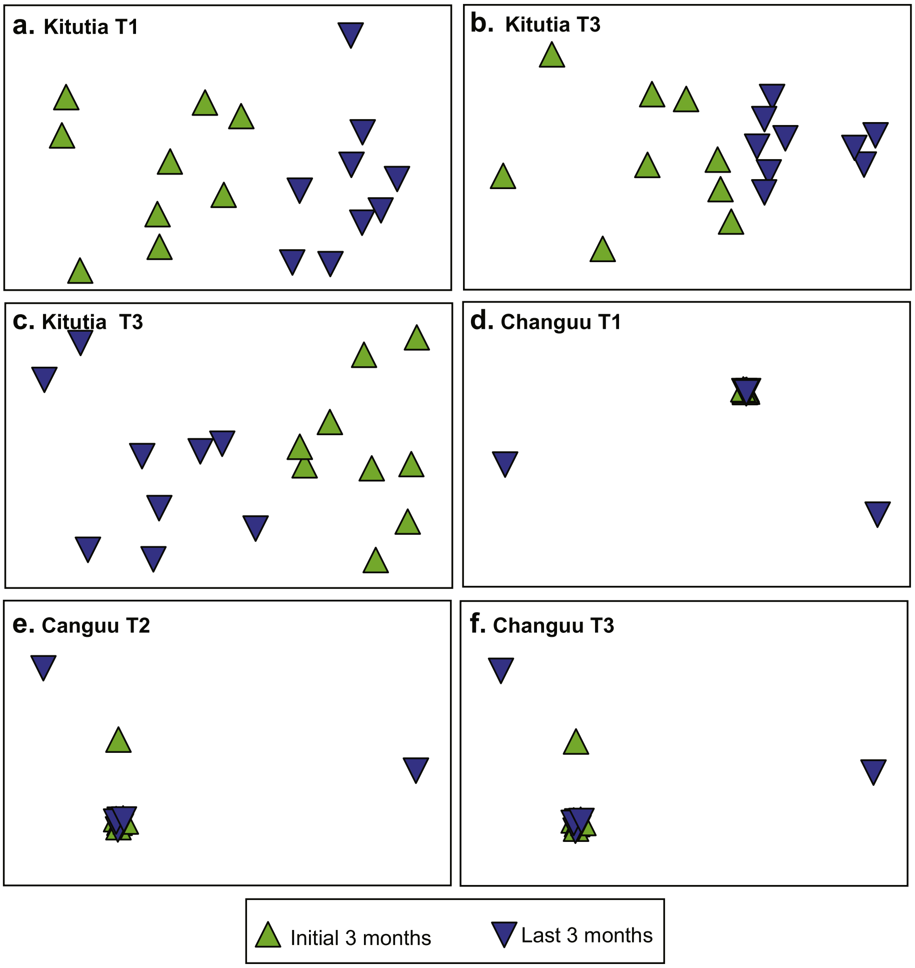


Fig. 5. Non-metric multidimensional scaling (nMDS) ordination of fish assemblage structure separated within treatments (A–F), based on fish density data at the experimental starting point and the last three months (10–12 m after transplantation). Analyses performed by Bray–Curtis similarities index using square root-transformed data of fish density.

central bare sub-plot of T3 as compared to T1 and T2. Species identified were *Pocillopora damicornis* ($0.7/m^2$), *Porites rus* ($0.75/m^2$), *Acropora humilis* ($0.50/m^2$) and several othercoral species that were too small and grouped together as unidentified species ($2.0/m^2$).

4. Discussion

This study is one among many others aiming at developing appropriate methodologies and site specific restoration protocols for denuded reef areas around the world. Here we recorded in both studied sites high survival and growth rates of transplanted coral colonies, coupled with increased densities of fishes and recruitment of corals with time. Additionally, there was no significant difference in transplant detachment rates for the two attachment protocols used. The branching *Acropora* species showed the highest growth rates (as in other studies; Yap et al., 1992), a characteristic feature for coral species employing fragmentation as a major asexual reproduction mode in their life history patterns (Bothwell, 1982; Highsmith, 1982). The observed fast growth rates of transplanted species may be attributed to the use of large sized fragments in transplantation (Highsmith, 1982; Bowden-Kerby, 2001; Lindahl et al., 2001). In contrast, *Millepora* sp. and *Pocillopora verrucosa* that were growing equally fast to *Acropora* species in nurseries (Mbije et al., 2010) showed slower growth rates after transplantation, while still high enough for natural reef conditions. These results provide further evidence for the argument that active coral restoration initiatives may bring back denuded coral reef areas to their original state (Lindahl, 2003; Rinkevich, 2005, 2006, 2008). Concomitantly, while some studies indicated that coral reef restoration through transplantation can be costly costs (Edwards and Gomez, 2007; Edwards, 2010), our results indicate that a large scale coral transplantation can also be done in developing countries at low costs with the available resources, less than one tenth of the costs as evaluated earlier.

Similar to recent documentation of environmental impacts on reef restoration (Shaish et al., 2010a), the Tanzanian coral transplants experienced two catastrophes, *Acanthaster planci* infestation and a major coral bleaching event. The unexpected infestation by crown-of-thorns starfish at Changuus' reef, immediately after colony transplantation, which was not documented in adjacent natural reef areas, may have been related to the response of resident organisms to newly arrived transplants. Similar results from transplantation experiments in the Red Sea (Horoszowski, personal communication, 2010) and South East Asia (Shaish et al., 2010a) showed that new transplants are prone to attacks by resident fish and corallivorous invertebrates that may eventually kill them. Starfish infestation impacted all coral species but the most affected species were *Pocillopora verrucosa*, *Porites cylindrica*, *Acropora muricata* and *Acropora nasuta*. Where as Harriott et al. (2003) discussed different theories for *A. planci* outbreaks, determining the

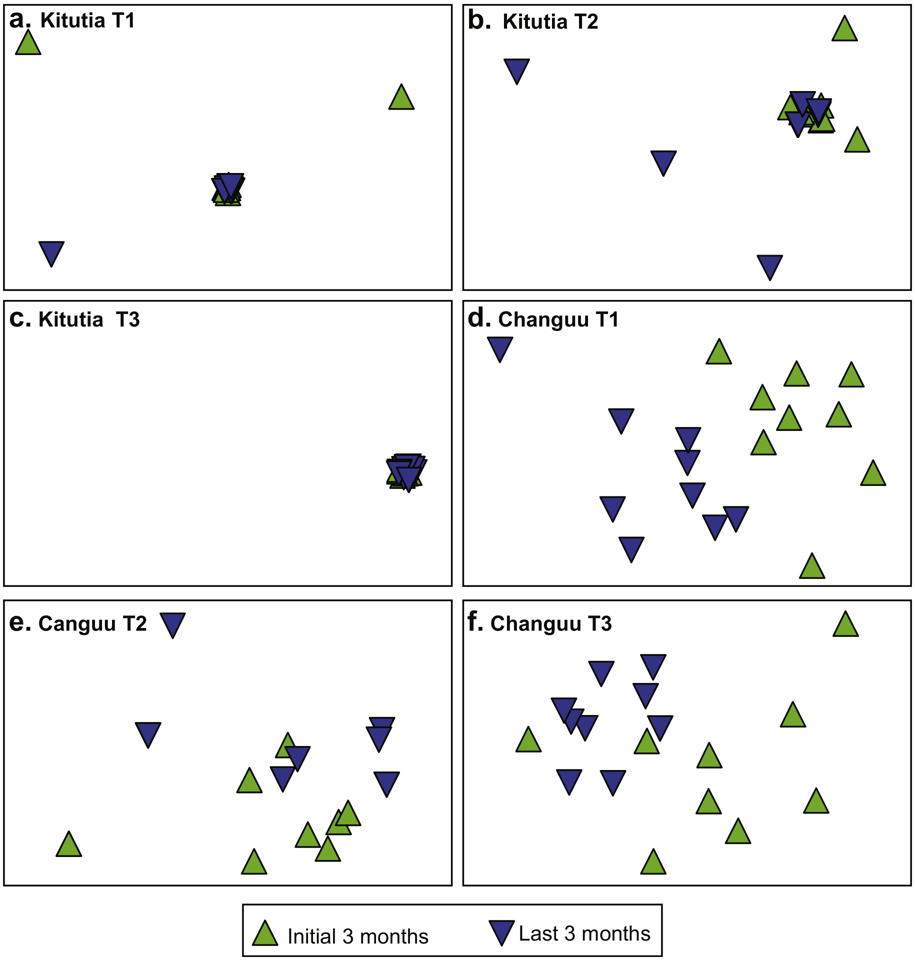


Fig. 6. Non-metric multidimensional scaling (nMDS) ordination of large invertebrate assemblage structure within treatments separation (A–F) based on invertebrate density data at the experimental starting point and the last three months (10–12 m after transplantation). Analyses performed by Bray–Curtis similarities index using square root-transformed data of invertebrate density.

reason for the specific outbreak at the transplantation sites is beyond the scope of this study. Damage to coral colonies by bleaching of transplants was the second major stressor, further documented in the studied Indo Pacific reef sites (Shaish et al., 2008, 2010a, b; Mbije et al., 2010). The most prominent bleaching episode during the first year after transplantation was part of the wide-spread bleaching event developing in the Western Indian Ocean (http://www.cordioea.org/bleachingalert, 2009). Generally, no significant mortality of transplants was associated with this phenomenon. However, Mafia Island and neighbouring areas of Kilwa, are among the remaining pristine fishing grounds of Tanzanian reefs and therefore highly prone to anthropogenic pressure. Some groups of fishermen have been invading the reefs, especially at night, and gain access to abundant coral reef fisheries resources (Wagner, 2004). The uprooting of transplanted fragments was probably a result of drag net activities that stopped after the case was reported to the park authority.

When comparing the initial and the last three months of the research for each treatment, we observed a significant difference in fish abundance for all three treatments in Kitutia reef but not in Changuu reef. In contrast, we observed no significant spatial variability for invertebrates at Kitutia reef between and within treatments, as opposed to Changuu reef where this was true only in T1 plots. Although we documented unclear patterns in invertebrate composition over time, the outcomes of this study further suggested that the primary reasons for the gradual variability in fish community composition within treatments for each site, over time, were the improved live coral cover and habitat structure caused by the transplantation as reported by Roberts and Ormond (1987) and Fowler et al. (1992). The above findings have been further supported by Cabaitan et al. (2008) and Ferse (2009) studies on the impacts of coral colonies on associated fish/invertebrates biota. This suggests that large-scale reef restoration projects may catalyse an increase in reef communities' species richness, abundance and composition; thus supporting faster attainment of original states.

Central bare sub-plots comparisons for initial and last three months revealed increased numbers of new spat belonging to the transplanted species, similarly to an earlier study on coral recruitment following coral transplantation (*Acropora muricata* in Mafia; Lindahl, 1998). There is a possibility for larval contribution from some on-site transplanted colonies during the studied period (Horoszowski-Friedman et al., 2011). However, the dominance of recruits from the three broadcasting *Acropora* species in all transplantation plots might indicate that the presence of the transplants *per se* may have acted as a cue for metamorphosing larvae (e.g., reef sounds; Vermeij et al., 2010) as changes in currents or fish communities.

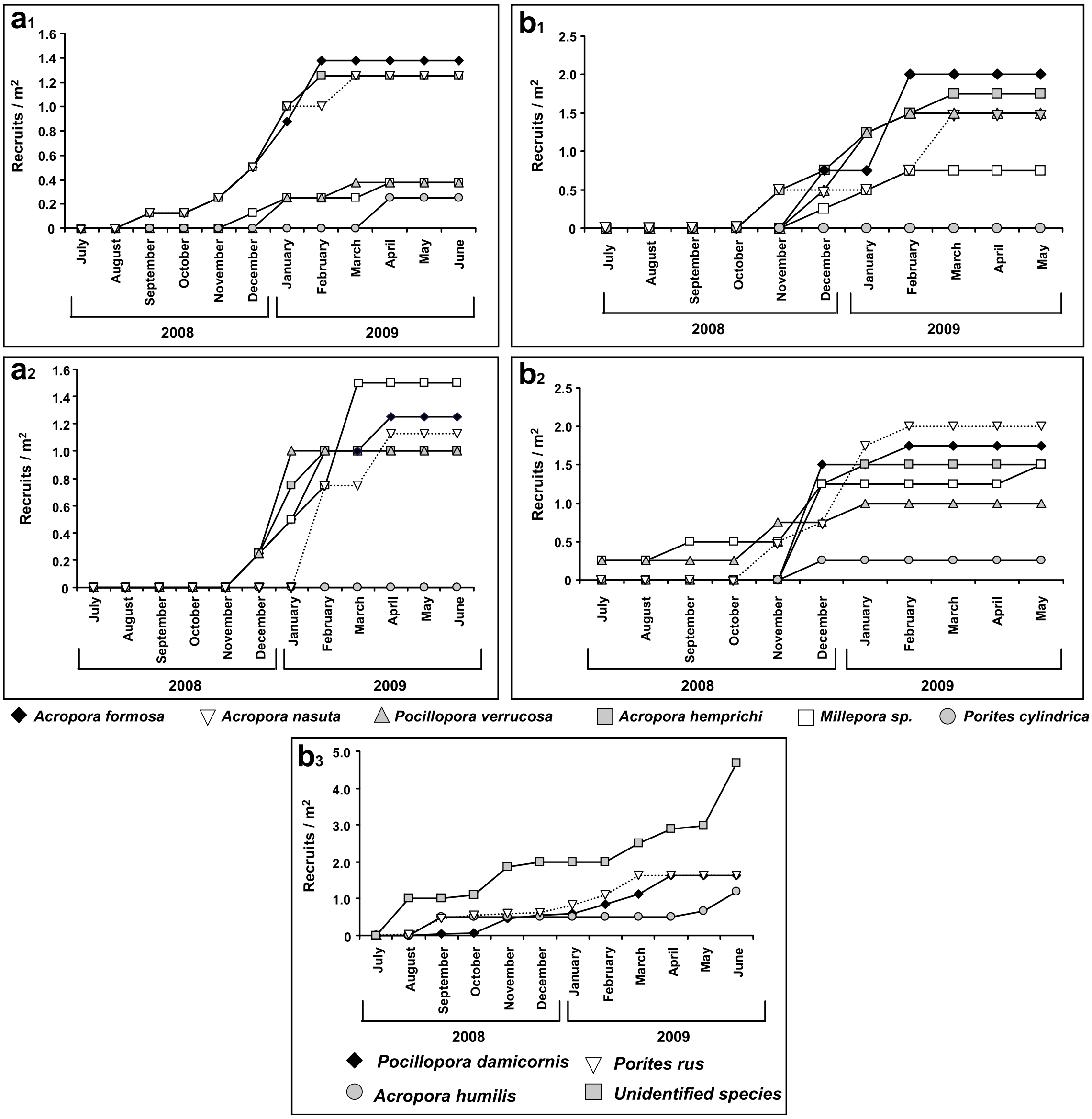


Fig. 7. Mean numbers of recruits in central bare plots. (a) Changuu reef in Zanzibar and (b) Kitutia reef in Mafia. 1–3 refer to treatments 1–3.

While this study provides the first insight into reef restoration through application of the two-step restoration protocol in East Africa, large-scale restoration projects that are urgently needed in Tanzania may require involvement of local communities (Wagner, 2004; Rinkevich, 2008; Mbije et al., 2010). Moreover, since many reefs in Tanzania have remained severely damaged after the 1997/98 El-Niño incident and after decades of anthropogenic disturbances including destructive fishing practices, large scale restoration measures, that take into account multi-species transplantation, are urgently needed to increase habitat complexity for reef dwelling organisms and for enhanced coral recruitment, altogether helping in conserving biodiversity. With the initiation of diverse studies globally, all attempting to address low cost applications in reef restoration (Clark and Edwards, 1995; Edwards and Clark, 1998; Bowden-Kerby, 2001; Lindahl, 2003; Fox, 2004; Raymundo et al., 2007; Garrison and Ward, 2008; Forrester et al., 2012), a ubiquitous approach is envisaged. On the other hand, special consideration should be given to associated social, economic and cultural themes (Christensen et al., 1996) that may vary between different reef sites. For example, the decision as to which and how much habitat should be restored may require discussions that involve reef stakeholders and, most importantly, local communities. Successful restorations are those that consider reef restoration methodologies appropriately adapted to local socio-economic limitations. Therefore, the future of large-scale coral reefs restoration of damaged areas in the Western Indian Ocean, as in other developing countries, is possible through applying relatively cheap and easily adaptable techniques with manpower involving surrounding local communities for sustainability.

Acknowledgements

This study is part of the PhD dissertation of N. Mbije, University of Haifa, Israel, and was supported by grants from the World Bank/GEF and the EU-INCO DEV projects. We thank the Institute of Marine Science in Zanzibar for field facilitation to E. Edward and G. Paz for field assistance and technical advice respectively.

Appendix A. Experimental design for transplanted coral colonies for each site; (I) Treatment 1 and (II) Treatment 2. T1 = *Acropora* species: *A. muricata. A. hemprichi and A. Nasuta* and T2 = All species: *Acropora nasuta, A. hemprichi, A. muricata, Millepora sp., Pocillopora verrucosa and Porites cylindrica.*

I			
Treatment 1	Distribution of coral fragments within plots (each 4 m^2)		
	Plot no.	Corals transplanted	Species
Transplantation lot 1 (36 m^2)	1	Genome 1	*Acropora muricata*
	2	Genome 2	*Acropora hemprichi*
	3	Genome 3	*Acropora nasuta*
	4	Mixed genomes	*Acropora muricata*
	5	Mixed species	3 *Acropora* species
	6	Mixed species	3 *Acropora* species
	7	Mixed species	3 *Acropora* species
	8	Mixed genomes	*Acropora hemprichi*
Transplantation lot 2 (36 m^2)	1	Mixed genomes	*Acropora nasuta*
	2	Genome 2	*Acropora muricata*
	3	Genome 1	*Acropora hemprichi*
	4	Mixed species	3 *Acropora* species
	5	Mixed genomes	*Acropora nasuta*
	6	Mixed species	3 *Acropora* species
	7	Genome 3	*Acropora muricata*
	8	Mixed species	3 *Acropora* species
Transplantation lot 3 (36 m^2)	1	Mixed species	3 *Acropora* species
	2	Mixed species	3 *Acropora* species
	3	Mixed species	3 *Acropora* species
	4	Mixed species	3 *Acropora* species
	5	Mixed species	3 *Acropora* species
	6	Mixed species	3 *Acropora* species
	7	Mixed species	3 *Acropora* species
	8	Mixed species	3 *Acropora* species

II			
Treatment 2	Distribution of coral fragments within lots (each 4 m^2)		
Transplantation for each of lots 1, 2 and (36 m^2)	Plot 1	Mixed species	All species
	Plot 2	Mixed species	All species
	Plot 3	Mixed species	All species
	Plot 4	Mixed species	All species
	Plot 5	Mixed species	All species
	Plot 6	Mixed species	All species
	Plot 7	Mixed species	All species
	Plot 8	Mixed species	All species

Appendix B. Major taxa of recorded fish species at Kitutia and Changuu reefs.

Family	Species	Site recorded
Pomacentridae	*Chromis dimidiata*	Kitutia and Changuu
	C. ternatensis	Kitutia
	Plectroglyphidodon lacrymatus	Kitutia
	Dascyllus trimaculatus	Kitutia and Changuu
	Cirrhilabrus exquisitus	Kitutia
	Chrisiptera unimaculata	Kitutia
	Stegastes nigricans	Kitutia and Changuu
	Abdefduf sexfasciatus	Kitutia and Changuu
	Chromis viridis	Kitutia
	Abdefduf sparoides	Kitutia
	Dascyllus aruanus	Kitutia
Labridae	*Halichoeres cosmetus*	Kitutia
	Gomphosus caeruleus	Kitutia
	Labrichthys unilineatus	Kitutia
	Pseudocheilinus hexataenia	Kitutia and Changuu
	Thalassoma amblycephalum	Kitutia
	T. hebraicum	Kitutia and Changuu
Chaetodontidae	*Chaetodon auriga*	Kitutia
	C. trifacsiatus	Kitutia
Scaridae	*Scarus sordidus*	Kitutia and Changuu
	Leptoscurus vaigiensis	Kitutia
Haemulidae	*Plectorhincus gaterinus*	Kitutia
Caesionidae	*Caesioca erulaureus*	Kitutia
Lutjanidae	*Lutjanus fluviflamma*	Kitutia
	Lutjanus kasmira	Kitutia
	Lutjanus bohar	Kitutia
Lethrinadae	*Lethrinus harak*	Kitutia
	Lethrinus nebulosus	Kitutia
Holocentridae	*Myripristis murdjan*	Kitutia

Appendix C. Major taxa of recorded invertebrate species at Kitutia and Changuu reefs.

Class	Species	Site recorded
Echinoidea	*Diadema setosum*	Kitutia and Changuu
	Diadema savignyi	Kitutia and Changuu
	Echinometra mathai	Kitutia and Changuu
	Echinothrix diadema	Kitutia and Changuu
Asteroidea	*Acanthaster planci*	Kitutia
	Culcita schmideliana	Kitutia
	Linckia guildingi	Changuu
	Pentaceraster mammillatus	Kitutia and Changuu
	Pentaceraster tuberculatus	Kitutia and Changuu
	Protoreaster lincki	Changuu
	Synapta maculata	Kitutia
	Tripneustes gratilla	Kitutia
Gastropoda	*Cypraea tigris*	Kitutia

References

Amar, K.O., Rinkevich, B., 2007. A floating mid-water coral nursery as larval dispersion hub: testing an idea. Marine Biology 151, 713–718.

Babcock, R.C., Baird, A.H., Piromvaragorn, S., Thomson, D.P., Willis, B.L., 2003. Identification of Scleractinian coral recruits from Indo-Pacific reefs. Zoological Studies 42, 211–226.

Baticados, D.B., 2004. Fishing cooperatives participation in managing nearshore resources: the case in Capiz, Central Philippines. Fisheries Research 67, 81–91.

Bongiorni, L., Giovanelli, D., Rinkevich, B., Pusceddu, A., Chou, L.M., Danovaro, R., 2011. First step in the restoration of a highly degraded coral reef (Singapore) by *in situ* coral intensive farming. Aquaculture 322–323, 191–200.

Bothwell, A.M., 1982. Fragmentation, as mean of asexual reproduction and dispersal in Genus *Acropora* (Scleractinia: Astocoeniida: Acroporidae) – a preliminary report. In: Proceeding of the 4th International Coral Reef Symposium, Philippines 2, pp. 137–144.

Bowden-Kerby, A., 1997. Coral transplantation in sheltered habitats using unattached colonies and culture corals. In: Proceeding of the 8th Coral Reef Symposium Panama 2, pp. 2063–2068.

Bowden-Kerby, A., 2001. Low tech coral reef restoration methods modeled after natural fragmentation processes. Bulletin of Marine Science 69 (2), 915–931.

Bruckner, A.W., Bruckner, R.J., 2001. Condition of restored Acropora palmata fragments off Mona Island, Puerto Rico, 2 years after the Fortuna Reefer ship grounding. Coral Reefs 20, 235–243.

Cabaitan, P., Gomez, E.D., Aliño, P.M., 2008. Effects of coral transplantation and giant clam restocking on the structure of fish communities on degraded patch reefs. Journal of Experimental Marine Biology and Ecology 357, 85–98.

Chou, L.M., Yeemin, T., Abdul-Rahim, B.G.Y., Vo, S.T., Alino, P.M., Suharsono, M., 2009. Coral reef restoration in the South China Sea. Galaxea 11, 67–74.

Clark, S., Edwards, A., 1995. Coral transplantation as an aid to reef rehabilitation: evaluation of a case study in the Maldive Islands. Coral Reefs 14, 201–221.

Cordio Bleaching Alerts, 2009. http://www.cordioea.org/bleachingalert.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18, 117–143.

Christensen, N.L., Bartuska, A., Brown, J.H., Carpenter, S., D'Antonio, C., Francis, R., Franklin, J.F., MacMahon, J.A., Noss, R.F., Parsons, D.J., Peterson, C.H., Turner, M.G., Moodmansee, R.G., 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecological Applications 6, 665–691.

Dudgeon, S., Aronson, R., Bruno, J., Precht, W., 2010. Phase shifts and stable states on coral reefs. Marine Ecology Progress Series 413, 201–216.

English, S.C., Wilkinson, B.V., 1994. Survey Manual for Tropical Fish Resources. Australian Institute of Marine Sciences, Townsville, p. 117.

Edwards, A.J., 2010. Reef Restoration Manual. Coral Reef Targeted Research and Capacity Building for Management Program, St Lucia, Australia, p. 166.

Edwards, A.J., Clark, S., 1998. Coral transplantation: a useful management tool or misguided meddling? Marine Pollution Bulletin 37, 8–12.

Edwards, A.J., Gomez, E.D., 2007. Reef Restoration Concepts and Guidelines: Making Sensible Management Choices in the Face of Uncertainty. Coral Reef Targeted Research and Capacity Building for Management Programme, St Lucia, Australia, p. 38.

Ferse, S.C.A., 2009. Multivariate responses of the coral reef fish community to artificial structures and coral transplants. In: Proceedings of the 11th International Coral Reef Symposium, pp. 1230–1234, 6–11 July 2008, Fort Lauderdale, FL 2.

Ferse, S.C.A., 2010. Poor performance of corals transplanted onto substrates of short durability. Restoration Ecology 18, 399–407.

Forrester, G.E., Taylor, K., Schofield, S., Maynard, A., 2012. Colony growth of corals transplanted for restoration depends on their site of origin and environmental factors. Marine Ecology. http://dx.doi.org/10.1111/maec.12000.

Fowler, A.J., Doherty, P.J., Williams, D.McB., 1992. Multi-scale analysis of recruitment of a coral reef fish on the Great Barrier Reef. Marine Ecology Progress Series 82, 131–141.

Fox, H.E., 2004. Coral recruitment in blasted and unblasted sites in Indonesia: assessing rehabilitation potential. Marine Ecology Progress Series 269, 131–139.

Franklin, H., Muhando, C.A., Lindahl, U., 1998. Coral culturing and temporal recruitment patterns in Zanzibar, Tanzania. Ambio 27, 651–655.

Garpe, K.C., Ohman, M.C., 2007. Non-random use of habitat by coral reef fish recruits in Mafia Island Marine Park, Tanzania. African Journal of Marine Science 29, 187–199.

Garrison, V., Ward, G., 2008. Storm-generated coral fragments—a viable source of transplants for reef rehabilitation. Biological Conservation 141, 3089–3100.

Guest, J.R., Dizon, R.M., Edwards, A.J., Franco, C., Gomez, E.D., 2011. How quickly do fragments of coral "self-attach" after transplantation? Restoration Ecology 19, 234–242.

Harriott, V., Goggin, L., Sweatman, H., 2003. Crown-of-thorns starfish on the Great Barrier Reef -current state of knowledge. Cooperative Research Centre, Reef Research Centre, Townsville, Australia, p. 202.

Highsmith, R.C., 1982. Reproduction by fragmentation in corals. Marine Ecology Progress Series 7, 207–226.

Hoegh-Guldberg, O., 2004. Coral reefs in a century of rapid environmental change. Symbiosis 37, 1–31.

Horoszowski-Friedman, Y.B., Izhaki, I., Rinkevich, B., 2011. Engineering of coral larval supply through transplantation of nursery-farmed gravid colonies. Journal of Experimental Marine Biology and Ecology 399, 162–166.

Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. Current Biology 17, 360–365.

Iwao, K., Wao, M., Omori., H., Taniguchi, H., Tamura, M., 2010. Transplanted *Acropora tenuis* (Dana) spawned first in their life 4 years after culture from eggs. Galaxea 12, 47.

Köhlin, G., Ostwald, M., 2001. Impact of plantations on forest use and forest status in Orissa, India. Ambio 30 (1), 37–42.

Levene, H., 1960. Robust tests for equality of variances. In: Olkin, J. (Ed.), Contributions to Probability and Statistics. Stanford University Press, Palo Alto, CA, p. 307.

Levi, G., Shaish, L., Haim, A., Rinkevich, B., 2010. Mid-water rope nursery – testing design and performance of a novel reef restoration instrument. Ecological Engineering 36, 560–569.

Lesica, P., Allendorf, F.W., 1999. Ecological genetics and the restoration of plant communities: mix or match? Restoration Ecology 7, 42–50.

Lewis, J.B., 1991. Testing the coral fragment size-dependent survivorship hypothesis for the calcareous Hydrozoan *Millepora complanata*. Marine Ecology Progress Series 70, 101–104.

Lindahl, U., 1998. Low-tech rehabilitation of degraded coral reefs through transplantation of staghorn corals. Ambio 27, 645–650.

Lindahl, U., 2000. Rehabilitation of Degraded Coral Reefs Through Transplantation of Staghorn Corals. Göteborg University, Sweden. (PhD dissertation).

Lindahl, U., 2003. Coral reef rehabilitation through transplantation of staghorn corals: effects of artificial stabilization and mechanical damages. Coral Reefs 22, 217–223.

Lindahl, U., Ohman, M.C., Schelten, C.K., 2001. The 1997/1998 mass mortality of corals: effects on fish communities on a Tanzanian coral reef. Marine Pollution Bulletin 42, 127–131.

Linden, B., Rinkevich, B., 2011. Creating stocks of young colonies from brooding-coral larvae amenable to active reef restoration. Journal of Experimental Marine Biology and Ecology 398, 40–46.

Lirman, D., Thyberg, T., Herlan, J., Hill, C., Young-Lahiff, C., Schopmeyer, S., Huntington, B., Santos, R., Drury, C., 2010. Propagation of the threatened staghorn coral *Acropora cervicornis*: methods to minimize the impacts of fragment collection and maximize production. Coral Reefs 29, 729–735.

Mbije, N.E.J., Spanier, E., Rinkevich, B., 2010. Testing the first phase of gardening concept as applicable tool in restoring denuded reefs of Tanzania. Ecological Engineering 36, 713–721.

Muko, S., Iwasa, Y., 2011. Optimal choice of species and size class for transplanting coral community. Journal of Theoretical Biology 273, 130–137.

Normile, D., 2010. UN biodiversity summit yields welcome and unexpected progress. Nature 330, 742–743.

Nzali, L., Johnstone, R., Mgaya, Y.D., 1998. Factors affecting scleractinian coral recruitment on a near shore reef of Tanzania. Ambio 27, 717–722.

Omori, M., Iwao, K., 2009. A novel substrate (the "coral peg") for deploying sexually propagated corals for reef restoration. Galaxea 11, 39.

Ortiz-Prosper, A.L., Bowden-Kerby, A., Ruiz, H., Tirado, O., Caban, A., Sanchez, G., Crespo, J.C., 2001. Planting small massive corals on small artificial concrete reefs or dead coral heads. Bulletin of Marine Science 69, 1047–1051.

Putchim, L., Thongtham, N., Hewett, A., Chansang, H., 2009. Survival and growth of *Acropora* spp. in mid-water nursery and after transplantation. In: Proceedings of the 11th International Coral Reef Symposium, Phi Phi Islands, Andaman Sea, Thailand, pp. 19–22.

Quinn, N.J., Kojis, B.L., 2006. Evaluating the potential of natural reproduction and artificial techniques to increase *Acropora cervicornis* populations at Discovery Bay, Jamaica. International Journal of Tropical Biology 54, 105–116.

Raymundo, L., Maypa, A., Gomez, E.D., Cadiz, P., 2007. Can dynamite-blasted reefs recover? A novel, low-tech approach to stimulating natural recovery in fish and coral populations. Marine Pollution Bulletin 54, 1009–1019.

Rinkevich, B., Loya, Y., 1983. Short term fate of photosynthetic products in a hermatypic coral. Journal of Experimental Marine Biology and Ecology 73, 175–184.

Rinkevich, B., 2005. Conservation of coral reefs through active restoration measures: recent approaches and last decade progress. Environmental Science and Technology 39, 4333–4342.

Rinkevich, B., 2006. The coral gardening concept and the use of underwater nurseries; lesson learned from silvics and silviculture. In: Precht, W.F. (Ed.), Coral Reef Restoration Handbook. CRC Press, Boca Raton, Florida, pp. 291–301.

Rinkevich, B., 2008. Management of coral reefs: we have gone wrong when neglecting active reef restoration. Marine Pollution Bulletin 56, 1821–1824.

Richmond, M.D., 2002. A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands. Sida/Sarec-UDSM, p. 461.

Roberts, C.M., Ormond, R.F., 1987. Habitat complexity and coral reef diversity and abundance on Red Sea fringing reefs. Marine Ecology Progression Series 41, 1–8.

Shafir, S., Rinkevich, B., 2008. The underwater silviculture approach for reef restoration: an emergent aquaculture theme. In: Schwartz, S.H. (Ed.), Aquaculture Research Trends. Nova Science Publications, New York, pp. 279–295.

Shafir, S., Rinkevich, B., 2010. Integrated long term mid-water coral nurseries: a management instrument evolving into a floating ecosystem. Mauritius Research Journal 16, 365–379.

Shaish, L., Levy, G., Gomez, E., Rinkevich, B., 2008. Fixed and suspended coral nurseries in the Philippines: establishing the first step in the "gardening concept" of reef restoration. Journal of Experimental Marine Biology and Ecology 358, 86–97.

Shaish, L., Levi, G., Katzir, G., Rinkevich, B., 2010a. Employing a highly fragmented, weedy coral species in reef restoration. Ecological Engineering 36, 1424–1432.

Shaish, L., Levi, G., Katzir, G., Rinkevich, B., 2010b. Coral reef restoration (Bolinao, the Philippines) in the face of frequent natural catastrophes. Restoration Ecology 18, 285–299.

Soong, K., Chen, T., 2003. Coral transplantation: regeneration and growth of *Acropora* fragments in a nursery. Restoration Ecology 11, 62–71.

Vermeij, M.J.A., Marhaver, K.L., Huijbers, C.M., Nagelkerken, I., Simpson, S.D., 2010. Coral larvae move toward reef sounds. PLoS One 5, 1–4.

Wagner, G.M., 2004. Coral reefs and their management in Tanzania. Western Indian Ocean Journal and Marine Science 3, 227–243.

Wagner, G.M., 2005. Coral reefs. In: Tanzania State of the Coast Report 2003: The National ICM Strategy and Prospects for Poverty Reduction. Tanzania Coastal Management Partnership, Dar es Salaam, pp. 1–4.

Wallace, C.C., Bull, G.D., 1981. Patterns of juvenile coral recruitment on a reef front during a spring-summer spawning period. In: Gomez, E.D., Birkeland, C.E., Buddemeier, R.W., Johannes, R.E., Marsh, J.A., Jr., Tsuda, R.T. (Eds.), Proceedings of the 4th International Coral Reef Symposium 2. Marine Sciences Center, University of the Philippines, Manila, pp. 345–350.

Wells, S.M., Alcala, A.C., 1987. Collecting of corals and shells. In: Salvat, B. (Ed.), Human Impacts on Coral Reefs: facts and recommendations. Antenne Museum EPHE, French Polynesia, pp. 13–27.

Wells, S., 2009. Dynamite fishing in northern Tanzania – pervasive, problematic and yet preventable. Marine Pollution Bulletin 58, 20–23.

Yap, H.T., Alino, P.M., Gomez, E.D., 1992. Trends in growth and mortality of three coral species (Anthozoa, Scleractinia), including effects of transplantation. Marine Ecology Progress Series 83, 91–101.