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

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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

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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,