Volume 6, Issue No.1

KENYA Aquatica

A Scientific Journal of Kenya Marine and Fisheries Research Institute

KMFRI

Editorial

The current Kenya Aquatica Vol. 6(1) features application of local technology on coral reef rehabilitation; performance of locally manunfactured fish dryers, some aspects of Blue Economy, and the role of the ocean in climate change mitigation and adaptation in Kenya.

Many thanks to members of the Kenya Aquatica Editorial Board and the unwevering support we continue to receive from KMFRI, Pwani University and the Technical University of Mombasa. This year we have been fortunate to receive additional financial support from Pew Fellowship programme based at KMFRI. We are most thankful to Dr. James Kairo, Pew Fellow (2019), for providing this support that led to the successful production of the current Volume.

Volume 6(1) contains two papers on the restoration of degraded coral reef and the socio-economic impact of reef rehabilitation. Two more papers feature comparison between the solar tunnel dryer and the traditional rack dryer as well as the performance of two dryers - solar tunnel and open air rack. This Volume also features a short communication and a commentary on emerging areas of sea floor mapping and inclusions of ocean climate solutions in Kenya's Climate Change Agenda.

The Editorial Board acknowledges various reviewers of the manuscripts led by Prof. Leonard Chauka of University of Dar-es-Salaam - Institute of Marine Sciences based in Zanzibar, Tanzania.

About Kenya Aquatica

Kenya Aquatica is the Scientific Journal of the Kenya Marine and Fisheries Research Institute (KMFRI). The Aim of the Journal is to provide an avenue for KMFRI researchers and partners to disseminate knowledge generated from research conducted in the aquatic environment of Kenya and resources therein and adjacent to it. This is in line with KMFRI's mandate to undertake research in marine and freshwater fisheries, aquaculture, environmental and ecological studies, and marine research including chemical and physical oceanography.

Manuscripts may be submitted to the Chief Editor through Director@kmfri.co.ke

Disclaimer: Statements in the Kenya Aquatica reflect the views of the authors and not necessarily those of KMFRI or the Editor

KENYA AQUATICA
SCIENTIFIC JOURNAL OF THE KENYA MARINE AND FISHERIES RESEARCH INSTITUTE
Volume 6, Issue No.1
2021

Subscription Information
The Kenya Aquatica is published semi-annually. It is an open access journal available free online at www.kmfri.co.ke
ISSN 2077-432X (print)
ISSN2077-432X-4-1

ISSN 2617-4936 (online)
ISSN2617-4936-4-1

Hard copies may be obtained free of charge from the Kenya Marine and Fisheries Research Institute.

Submitting Articles
Submissions to the Kenya Aquatica Journal are accepted year round for review.

Kenya Aquatica Journal. Vol. 6, No. 1, pp.01-16, 2021

Low-Tech, Community-Accessible Method to Restore a Degraded Reef, in Wasini Island, Kenya

Jelvas M. Mwaura* and Juliet F. Karisa
Kenya Marine and Fisheries Research Institute, P.O. Box 81651-80100, Mombasa, Kenya,
E-mail: director@kmfri.co.ke
Corresponding author: *Email: jmwaura@kmfri.co.ke

Abstract

Coral reefs are among most diverse and productive ecosystems on earth; providing essential services such as supporting fisheries and tourism sectors, thereby contributing to food security, job creation, and economic development. However, around the world coral reefs are in decline and degraded state due to a combination of human and natural factors. Coral reef restoration is seen a tool that can be used to return the dying reefs and increase their resiliency Techniques for active restoration using coral farming and transplantation on artificial reef structures have been well developed and proved to be viable for reef rehabilitation of degraded reefs, yet are rarely practiced. A pilot low-tech, community-accessible reef restoration project was implemented in Wasini community managed area, Kenya. The aim was to rehabilitate degraded reef areas using artificial reef structures. Here, we describe the steps involved in coral rehabilitation and the resulting outcomes. These steps include: 1) local community and other stakeholder mobilization and training, 2) identification of degraded reef areas, 3) Substrate modification and nursery-bed constructions, 4) Raising nursery grown corals, and 5) Coral transplantation on natural denuded reef rocks and concrete blocks, and 6). Monitoring and maintenance of transplanted corals. Our findings show that this community-based coral restoration is successful, with over 77% of corals transplanted on artificial reef structures surviving after one year. Additionally, the fish abundance observed around the concrete reef structures deployed was three-fold compared to the nearby natural reefs. The low-tech, community-accessible method demonstrated here is promising and transferable to communities for application in restoring degraded reef areas with similar conditions.

Keywords: Coral transplantation, community conservation areas (CCAs), climate change, community-based reef restoration, Kenya

Introduction

Coral reefs are among the most productive and biologically diverse ecosystems in the world; they provide goods and services such as fish habitats and coastal protection that contribute to food security, livelihoods and sustainable economic growth for hundreds of millions of people in form of artisanal fisheries and the tourism industry. The estimated value of Kenya's marine ecosystems is around US$ 2.5 billion per year (some 4% of its GDP), of which 70% is from tourism and fisheries, which are highly dependent on healthy reef ecosystems (Obura *et al.,* 2017). Tourism and fisheries are the two primary sources of livelihoods for local coastal communities. Coral reefs also provide coastal communities protection from sea level rise and extreme weather events such as tsunamis, thereby serving as natural physical buffers.

However, just like in many parts of the Western Indian Ocean (WIO), Kenyan coral reefs have suffered from the cumulative impacts of human activities, resulting in long-term decline (Wilkinson 2008; Obura *et al.*, 2017). Anthropogenic impacts include local stressors such as over fishing, land-based pollution, and global stressors such as climate change (Hoegh-Guldberg *et al.,* 2017; Mwaura *et al.,* 2017). Climate change-associate coral bleaching and mortality now represent the greatest threat to coral reefs, over and above the many local threats affecting coral reefs (McClanahan *et al*., 2000). In Kenya, recent reef monitoring have shown that over 70% of coral reefs are in a poor status (0-25% live coral cover) and less than 5% are in good condition (30-60%) (Obura *et al,* 2017). The low status of live coral cover in most reefs are due to unusually higher ocean temperatures that cause stress to corals that results to massive death of susceptible corals (Fig. 1). Over the last four decades, large-scale coral bleaching events have been recorded since 1997/98, 2010, 2012, and recently in 2016, with many reefs experiencing very little natural recovery (Gudka *et al.,* 2018). Other destructive fishing methods such as beach seine and spear gun fishing have also impacted the reef framework, leaving vast areas of unconsolidated rubbles and unsuitable for coral recruitment (Mangi & Roberts, 2006). In this situation, unconsolidated rubble persists, coral recruitment is lost, fish habitat and function are greatly reduced (Raymundo *et al*., 2007; Cruz *et al*., 2014; Grimsditch *et al.,* 2016). Recovery of corals after large-scale bleaching and widespread use of destructive fishing methods often slows down and, in some areas, complete failure to re-establish is a reality in the field (Gudka *et al.,* 2018). Corals require approximately 15 years to recover, suggesting that reliance on natural coral recovery could drive corals into extinction within the next decades (Sheppard, 2003). With bleaching projected to become more frequent and intense in the future, it is unlikely for most reefs to recover unassisted (Sheppard, 2003).

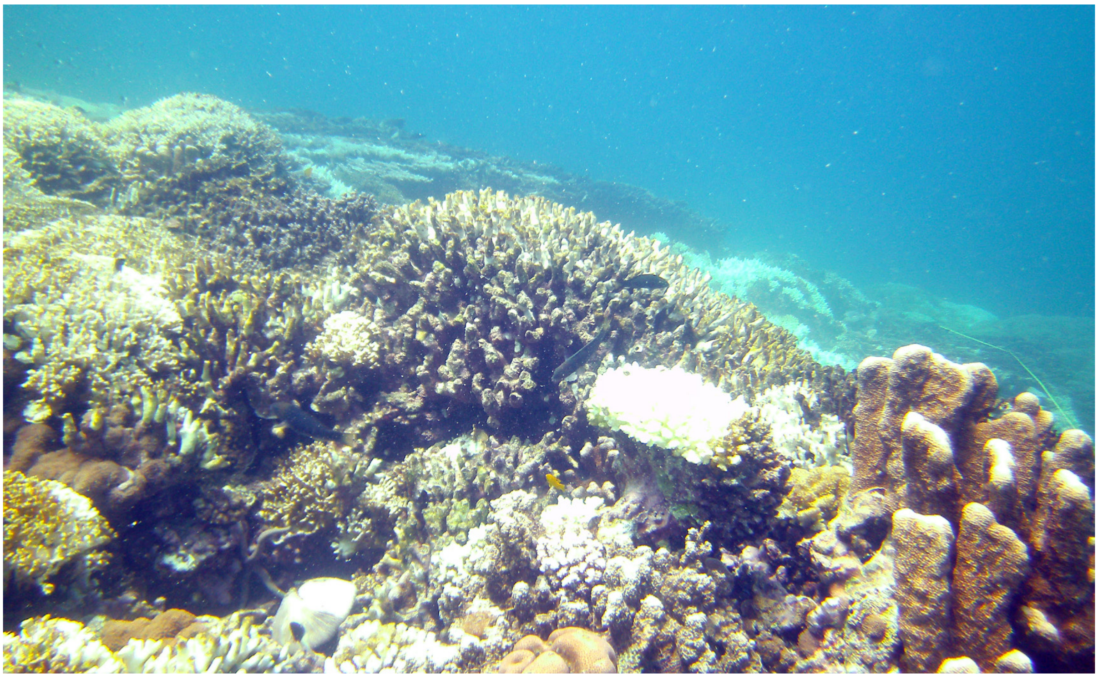

Fig. 1. An image of coral reef impacted by bleaching episodes in 2016. During this event, many reef corals bleached and died, resulting to loss of habitats that are critical for supporting fisheries and tourism sectors. Credit: Jelvas Mwaura.

Coral reef restoration is the process of assisting degraded reef recover physical and biological attributes that have been lost to a state that they can eventually become self-sustaining (Suding 2011; McDonald *et al*., 2016). Although activities to assist reef recovery have long focused on fisheries regulations and area-based management such as marine protected areas (MPAs) and locally managed community areas (McClanahan *et al.*, 2006; Mwaura, 2013), there is an increased recognition that these strategies need to be supplemented with other interventions such as active reef restoration projects (Edward & Gomez 2007). Various restoration methods have been developed in order to address the continuous decline of coral reefs worldwide (Precht, 2019). One of the most common approach for active restoration of degraded reefs that is predominantly sandy-rubble substrate is the addition of artificial reef structures to which corals can be transplanted (Edward 2010; Fox *et al.*, 2019), provided that the destructive methods are stopped and environment remains suitable (Edwards & Gomez 2007; Raymundo *et al*., 2007).

In East Africa, testing of transplantation of coral fragments on denuded reef substratum has been carried out successfully, demonstrating prospects of mitigating coral reef decline (Tamelander & Obura, 2002; Murage & Mwaura 2015; Mbije *et al.,* 2010). However, reef restoration can be generally expensive and technically challenging (i.e., choosing suitable restoration method and implementation approach), making it difficult for communities whom are expected to benefit to undertake it (Edwards 2010). A low-tech, community-accessible method is therefore necessary to ensure reduction of operational cost (including materials, time invested (labour cost) (Spurgeon & Lindahl 2000; Edwards 2010). For example, cleaning and maintenance of nursery corals and transplanted corals from biofouling organisms (e.g., sponges, algae and tunicates) requires considerable allocation of time invested (i.e., labour cost) in the total restoration project (Shafir *et al*., 2010; Johnson *et al*., 2011). A possible way to address this is to extensively involve the community in restoring of their own degraded reef, which would minimize the restoration cost by about 17% if the community puts labour as their in-kind contribution (Edwards *et al.,* 2010). Involving local community in reef restoration would also improve their sense of reef resources ownership, responsibility and ensure long-term success of the project as it relates heavily to their livelihoods (Trialfhianty & Suadi 2017).

In 2013, a community-based reef restoration was designed and implemented with funding from World Bank/Government of Kenya and executed through the Kenya Coastal Development Project (KCDP). This two-year rehabilitation project was not designed as a scientific experiment, but as means to engage the local communities to speed-up recovery of their degraded reef by deploying artificial reef structures (i.e., concrete blocks) onto which coral fragments were transplanted (Edward & Gomez 2007; Edward, 2010). It was assumed that engaging the local community in reef restoration may result to increased coral cover and fish abundance within the CCA, leading to improved fisheries resources and alternative livelihoods in the long-term.

The goal of this study was to test use of artificial reef structures (i.e., concrete blocks) as a new method easily accessible to local communities that could serve dual purpose-to create habitat suitable for fish recruitment while providing substrate for transplanting corals in a sandy-rubble reef. Here, we report the key steps involved in the implementation of the first successful low-tech, community-accessible method for reef restoration in Kenya and in the western Indian Ocean (WIO). Additionally, the study describes some of the results in terms of coral transplant survival, fish abundance and cost of the restoration project in addition to key lessons learnt during the process.

Materials and Methods

Site description

Reef rehabilitation project is located in Wasini Island of Kwale county; some 70 km from Mombasa city (Fig. 2). The work was based within the Community Conservation Area (CCA), and is managed by the community through the local Beach Management Unit. Today, Wasini Island has a resident population of 2080 people with 220 households in Wasini Island (*unpublished data*). Over 60% of the households in this island have for many generations been dependent on exploitation of the nearshore resources for both food and livelihoods through small scale or artisanal fisheries and tourism (Murage & Mwaura, 2015). The CCA was established in 2008 to help protect the reef and to assist in coral cover and local fisheries recovery. Although these reefs had been protected from destructive gears and fishing controlled for more than five years, the reef area was mainly of coral rubbles interspersed with some huge coral heads (i.e., *Porites* massive) covering about 3% and less fish (20 individuals per 250m^2 area) (Mwaura, 2013). Reef habitats with predominant sandy-rubbly substrate are mostly rehabilitated by addition of artificial reef substrate to which corals can be transplanted (Edward, 2010; Rinkevich 2005). On the basis of the above context, the author explored the prospects of a community-engagement for coral reef rehabilitation in partnership with other key stakeholders within Wasini CCA. This site was chosen on the basis of the following; 1. There is an existing area-based management plan that is regulating use of the marine environment, 2. high degree of reef degradation, 3., community commitment and willingness to support reef fishery management.

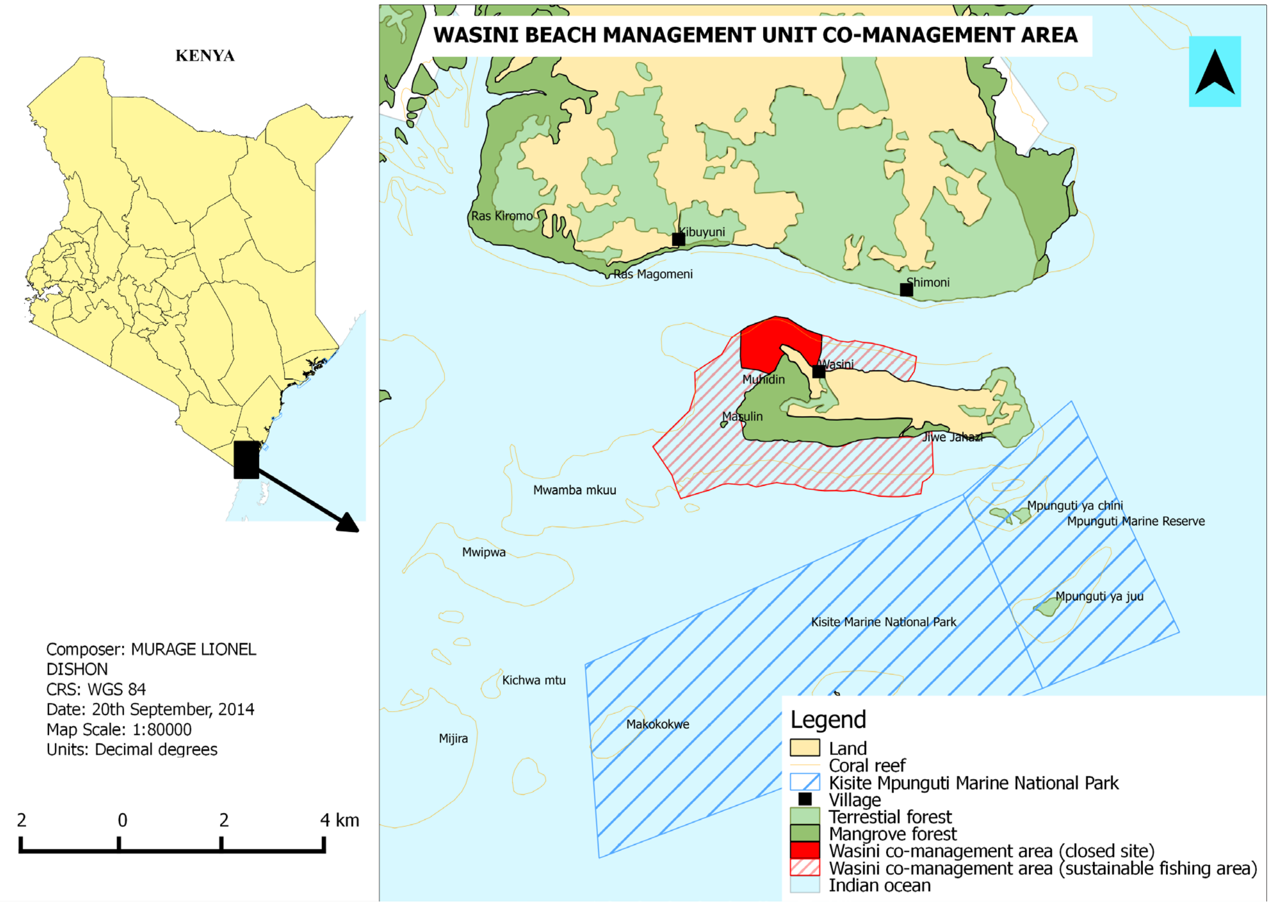

Fig. 2. Map of the community conservation area in Wasini Island, Southern coast of Kenya; where reef rehabilitation was undertaken in 2013.

i) ***Community sensitization meetings***

A few days prior to the scheduled reef restoration activity, an awareness workshop was organized in order to enhance cooperation and forge consensus among key stakeholders. More importantly, this activity sought to secure the support from local stakeholders as it will ensure the success and sustainability of the project. Locals were invited to participate in consultative meetings, of which an initial leveling of expectations of the reef restoration activity was carried out. They were village officials at Wasini island, BMU representatives, fishers, boat operators and representative from fisheries department and local NGOs. Training on basic coral biology and reef ecology, concepts of coral reef restoration, the activity objectives, transplantation techniques and criteria for choosing the coral fragments and restoration site was conducted prior to the implementation of restoration activities in order to raise awareness and facilitate understanding among the participants important for their participation in the restoration project (Fig. 3a). The lectures and field sessions were delivered by the authors and lasted for 2 days.

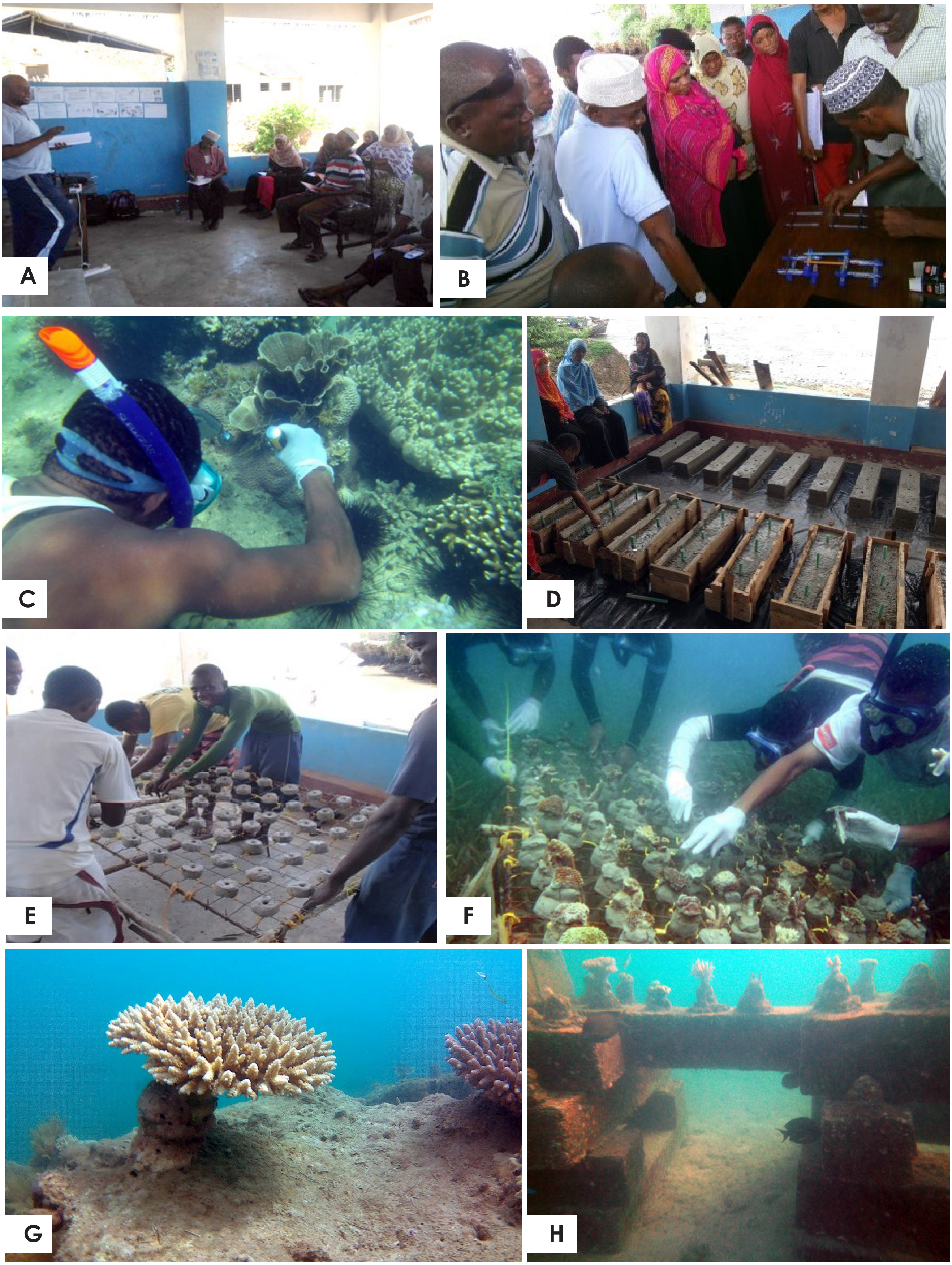

Fig 3. A) Awareness raising among local community members and reef managers, fisheries staff, B) participatory designing and construction of table nursery and concrete blocks, C) Collection of coral fragments, D. Construction of concrete blocks and cement discs, E. Construction of table mid-water nurseries, F) Outplanting and raising coral fragment in mid-water nurseries, G) Transplanted corals fixed on concrete substrate rock, and H) Transplanted corals and fish on artificial reef structure (pyramid concrete blocks).

The community-based coral restoration followed a modified protocol by Edwards (2010), that started with identification of degraded and donor reefs, followed by collection of coral fragments and setting up of nursery for culturing of corals, transplanting of nursery-grown corals and finally maintenance and monitoring of transplanted site (see schematic diagram in Figure 4).

ii) ***Establishment of coral nurseries and construction of artificial reef structures***

The most common and effective approach to coral reef restoration is coral gardening (Young *et al*., 2012. Corals are grown in an intermediate nursery phase, before being transplanted for restoration. In this initial phase, coral are fragmented and grown in mid-water nurseries, before they are transplanted at reasonable size onto stable hard substrate in the second phase. The nursery is usually deployed in habitat similar to recipient sites, and provides maricultured corals with an acclimation period essential for increasing post-transplantation survivorship and growth (Rinkevich, 2005).

The "coral gardening" concept (Rinkevich, 2006) was adapted for application in the restoration site, and centered on a two-step approach; the nursery growing of hundreds coral fragments (nubbins) for 6-8 months and the later transplantation of nursery-grown corals on recipient reef sites, either on natural denuded reef substrates or artificial reef structure (i.e., made using concrete blocks or coral boulders). Coral nursery tables were constructed using 20mm diameter round-bar metal frames elevated to 0.5 m above the substrate (Fig. 3c). Plastic mesh nets were mounted taunt across the tops of the nursery tables to facilitate the attachment of coral fragments, as well as reduce sediment accumulation around the base of the attached fragments. Artificial coral substrata were made using a 50:50 sand-cement mixture. Palm–sized balls of the mixture were hand-pressed into a small circular disk with a thumb depression on the center for coral fragment attachment, following the design from other similar studies (Clark & Edward, 1995; Soong & Chen, 2003).

Construction of artificial reefs consisted of making concrete block moulds that was placed on the sandy beach adjacent to the site (fig. 3e). About 10 moulds were constructed each with dimension of 20*20*150 cm. A concrete mix was made from three parts aggregate (predominantly coral boulders, with a particle size of 2-20cm) mixed with three buckets of sand and one bag of normal cement. The concrete mix was then poured into moulds and left on the beach to dry for 1-2 weeks. About 100 concrete blocks were then transported and deployed at the site using boats owned by community. Four divers then maneuvered the blocks and assembled them to form a pyramid reef structure at the site, where they were left ready for coral transplantation (Fig. 3h).

iii) ***Coral fragments collection and transplantation, monitoring and maintenance***

Coral fragments were collected by the authors and trained community members by cutting off or chopping from the parent- colonies manually using a hand-held hammer and chisel from a donor reef situated approximately 1km from restoration site (Fig. 3c, Fig.4, Step 2). The donor site was chosen on the basis that it has abundant and suitable coral species, suggesting to be a resilient reef from previous bleaching impacts (Mwaura, personal observation). To avoid collateral damage to the donor reef, less than 10% of each colony was fragmented (Epstein *et al*., 2001). Additionally, loose coral fragments ("coral of opportunity") lying on the seafloor were also collected as they would otherwise perish from being buried in soft sediments or swept about by currents. Coral fragments collection was mainly on branching-growth forms (e.g. *Acropora, Porites* branching, *Stylophora*) as they were predominant in the source reef, but other growth forms (*Cyphastrea*, *Echinopora, Platygyra*, *Goniopora, Diploastrea*, e.t.c) were also collected. Upon removal from the donor reef, the harvested fragments were immediately placed in 20 litre plastic buckets filled with sea water. The buckets were transported to restoration site using a speed-boat, laid and left in situ overnight at suitable site (3-4m deep).

With the help of about 20 local participants, the coral fragments ranging from 2-4cm were then fixed onto cement discs already secured on the nursery tables placed at depths of 4-5m (fig. 3e, fig. 4 step 3). Approximately 8,300 coral fragments were reared in 4 mid-water nurseries for 6 months. The maintenance which involves cleaning off debris, sponges and/or algae on base of transplanted corals was undertaken by ten community members on weekly basis. During this period of rearing coral fragments in mid-water nurseries, calm water conditions were experienced and the corals remained fixed in their holdings.

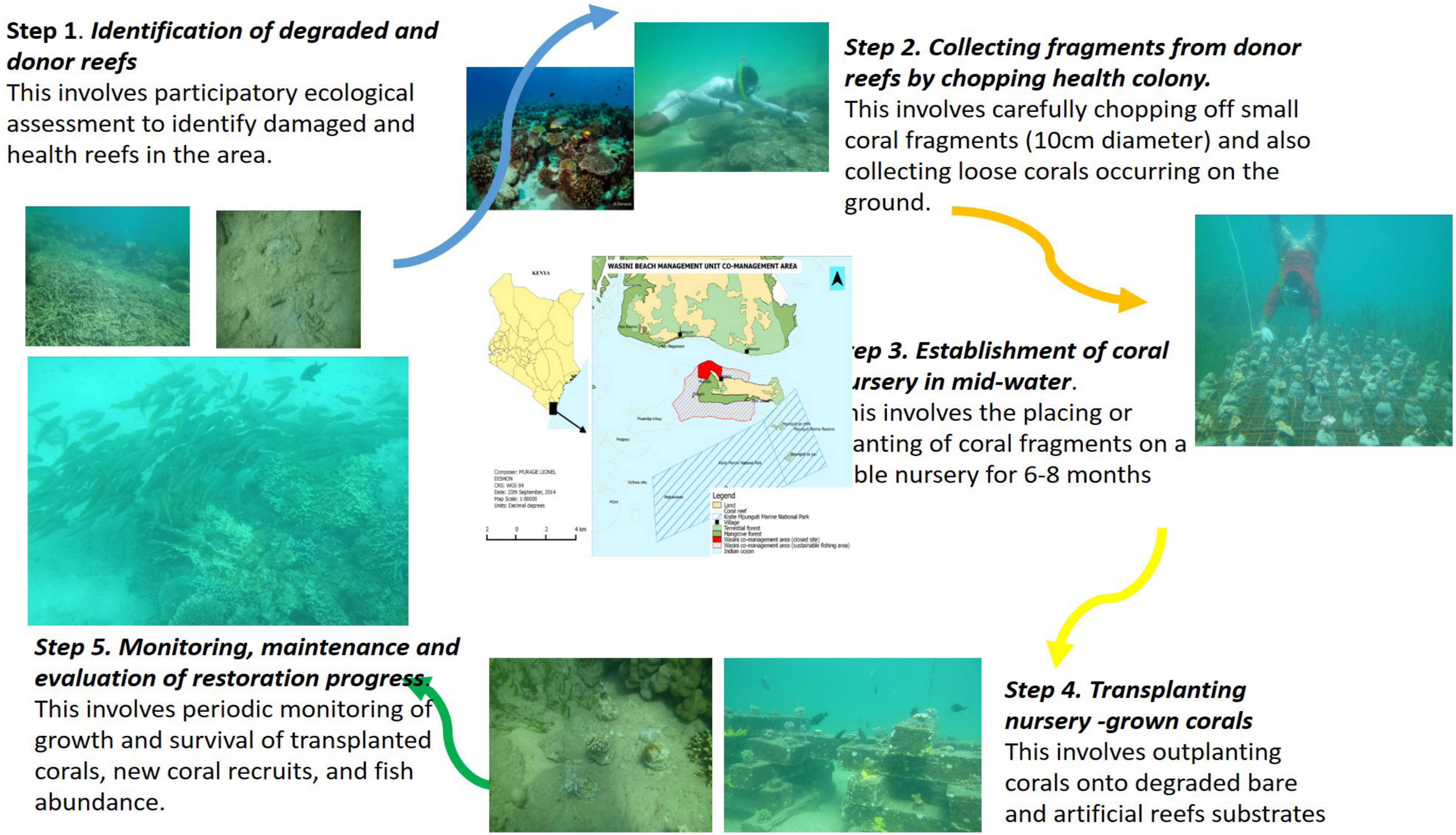

Fig. 4. A schematic diagram showing 5 important steps of the adapted community-based restoration protocol.

Following methods described in several studies (Shafir & Rinkevich 2008; Ng, *et al*., 2016), the live coral fragments of different growth forms were removed from the mid-water table nurseries, cleaned of foulers and transplanted onto deployed artificial reef structure surfaces (Fig.3i; Fig.4 step 4). The transplantation was performed by trained local community members by attaching the disc to the substrate surface using cement-sand mixed up with seawater. The fragments were placed at 20-30 cm distance apart and only 491 coral fragments were tagged for monitoring their survivorship every two months for one year. Corals were considered alive unless no living tissue was observed. Periodic cleaning and maintenance of transplanted corals was carried out by trained local community members, by removing recruiting algae and foulers (e.g., sponges, tunicates) on the artificial/concrete substrate and amongst the coral's nubbins using a small-hand brush (fig. 4 step 5). The cost of the whole restoration efforts was estimated following approach described in Edwards (2010). Using this estimate, costs of each activities was scored broadly and overall cost done per unit area (ha) were calculated.

Results

Community participation in regular maintenance of the transplanted corals

Through the active participation of local community members, over 8,000 nursery-grown corals were transplanted on concrete reef structures and assisted in monitoring part of the transplants (n=491) for one year. Aside from the monitoring, maintenance cleaning of transplanted corals was undertaken on weekly basis by trained local communities. After one year, the overall survival of the coral transplants ranged between 51-98% on 21 genera (Table 1, plate 1a), with an average of high survivorship of 77.1%. Higher mortalities was recorded in coral genera such as *Pocillopora Echinopora* and *Pachyseries*. Massive forms such as *Porites*, *Astreopora, Galaxea, Lobophylia, Platygyra, Favia* and *Favites* exhibited higher survivorship (75-100%). Generally, six months after transplantation, 66% of the transplants had survived. However, most transplant deaths during the initial months were attributed to dislodgement from the concrete or bare natural substrate due to poor cementing and accidental knocks/detachment by community members during maintenance of fragments rather than natural death. Coral cover at the transplant site increased from 5% to 30% and generic richness increased with new recruits of *Seriatopora* and *Stylophora*.

The relatively high survival of transplanted corals could be attributed to the high frequency of maintenance effort (i.e., once a week for 12 months) by the community members, which included scrubbing off the biofouling organisms and cleaning of fragments using small brushes to avoid algae-overgrowth.

Table1. Percentage of coral survival rates

Coral genus	Initial number of transplants	Live transplant observed	Survival rate (%)
Acanthastrea	3	3	100.0
Cyphastrea	7	7	100.0
Diploastrea	8	7	87.5
Echinopora	91	56	61.5
Favia	23	22	95.7
Favites	17	15	88.2
Goniopora	5	5	100.0
Hydnophora	34	32	94.1
Acropora	120	97	80.8
leptastrea	9	8	88.9
Lobophylia	4	3	75.0
Merulina	12	9	75.0
Montipora	23	22	95.7
Oxypora	30	28	93.3
Pachyseris	5	3	60.0
Pavona	17	15	88.2
Pectinia	23	18	78.3
Platygyra	34	32	94.1
Pocillopora	104	54	51.9
Podabacia	20	15	75.0
Porites	16	16	100.0
Turbinaria	6	4	66.7
Overall	611	471	77.1

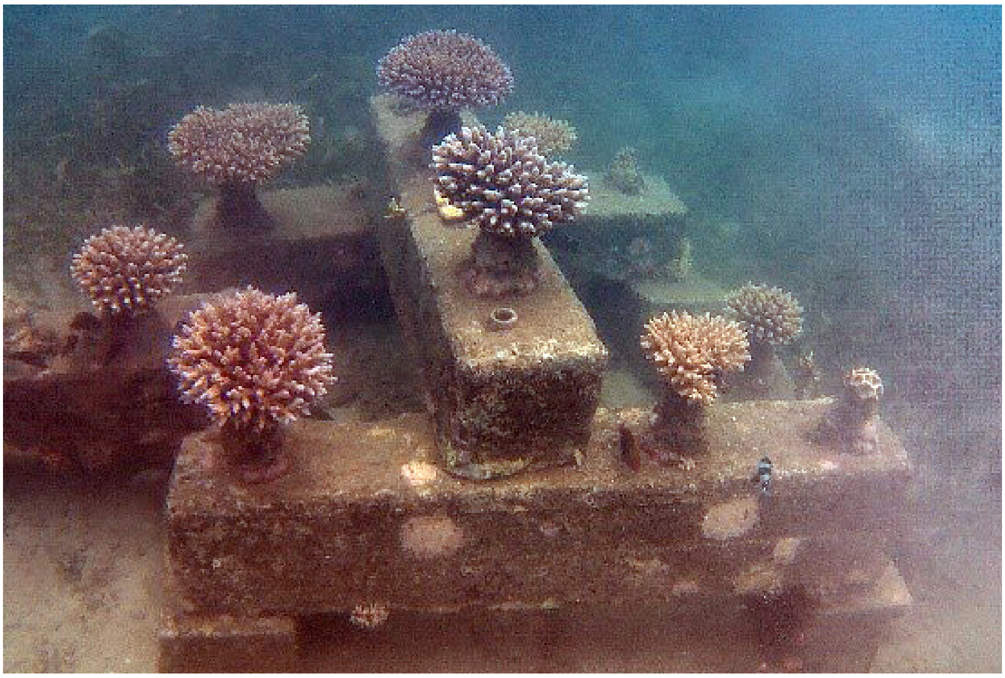

Plate 1. View of artificial reef structure at rehabilitated site upon which corals have been transplanted after one year.

Fish abundance

Initial field observation after transplantation of corals was rapid colonization of artificial reef structures by fish and macro-invertebrates' taxa (plate 1b). The deployment of artificial reef structures and subsequent attaching corals has created a new habitat for fish breeding and observable increase in fish populations has become an attraction to visiting tourists, thereby creating an alternative source of income for Wasini Village through ecotourism.

Plate 2. Artificial concrete structures with view of fish concentrations after one year *Operational cost of community-based restoration project*

The breakdown of expenditures of this community-based coral restoration work starting from raising community awareness to maintenance and monitoring of the transplanted corals on artificial reef structures is shown in table 2. The total coast is estimated at US$ 72,300 which is excluding the in-kind labour support by the community members (Table 2). The bulk of this amount was mainly spent on hired labour and boat rentals, that were free available as community members provided their own personal boats and snorkeling gears. High labour intensity required in restoration such as in maintenance and cleaning of fouling organisms around transplanted corals was provided in-kind by participating members.

	Cost estimates for establishing and implementing community-based reef restoration at Wasini, Kenya. Cost in US dollars		
	List of Activities	With Community Participation	Without Community Participation
		Total cost	Total cost
`	Training of community members(lecture and field session)	51,080	51,080
1	Awareness raising/sensitization workshops (40 participants)		
	Logistics(transport, materials, staff travel, subsistence)		
	Training community divers		
	Stationaries and T-shirts		
2	Set up, monitor and manage nursery	9,600	9,600
	Construction of nurseries (cable wires, steel rods)		
	Site selection for degraded and donor reef sites		
	Deployment of table nurseries		
	Labour (30 people) for 12 weeks	in-kind	5,400
3	Artificial reef structure construction	5,420	5,420
	Materials (sand, cements, timbers, rock boulders)		
	Logistics (transport, boat))		
	Labour (30 people) for 7 days	in-kind	3,150
4	Transplantation of nursery grown corals	3,900	3,900
	Boat fuel		
	Logistics (transport, materials, staff travel, subsistence)		
	Travel of trainers		
	Lunches and refreshment		
	Transplantation of nursery-grown corals		
	Labour (30 people) for 7 days	in-kind	3,150
5	Monitoring and maintenance	2,300	2,300
	Boat fuel		
	coral Transplant maintenance and management		
	Lunches and refreshment		
	Logistics (transport, materials, staff travel, subsistence)		
	Labour (10 people) for one year (48 weeks)	in-kind	7,200
	Total cost	**72,300**	**91,200**

Table 2. Cost estimates (in US $) for establishing and implementing community-based reef restoration at Wasini, Kenya.

Discussions

The coral reefs of Wasini Island are an important fishing ground that directly support more than 4000 fisher folks (Murage & Mwaura 2015). The reefs have been impacted by cumulative stressors (e.g., destructive fishing practices and coral bleaching events) and did not exhibit natural recovery for many years (Mwaura unpublished data). Instead, the reefs have continued to be predominantly of unstable coral rubbles which limit coral recruitment and growth (Grimsditch *et al.,* 2016). The project evolved over three years, seeking to engage local communities and developing cost-effective and efficient method to restore this degraded reef. To achieve this, this pilot study used concrete blocks as artificial reef structures to rehabilitate the reef that was mainly composed of sand and loose coral rubbles, as a mean to restore corals and fish. After one year, coral survival rates were relatively high (50-98%) and will serve to contribute as the source of coral larvae at the site in future. These high survival rates of transplanted corals can be attributed to intensive and periodic maintenance and cleaning of fouling organisms and algae by the participating local community. A similar study by Forrester *et al.,* (2011) in the Virgin Islands shows that higher survival of coral transplants is mostly related to avoidance of adverse conditions including algal overgrowth. This low-tech coral restoration project demonstrates that a degraded reef with sandy-rubble field can be successfully be repopulated with corals by local community.

Artificial reef structures deployed in reef restoration have been reported to not only provide substrate for coral attachment, but also create habitat on rubble fields (Raymundo *et al*., 2007), to offer refuge for sheltering and accumulation of fish and sessile organisms (Lindahl *et al*., 2001; Marzinelli *et al*., 2009). However, it seems that artificial reefs are not considered a promising restoration approach by restoration ecologists given the poor number of publications dealing with coral reef restoration (Abelson, 2006). One year after coral transplantation on artificial concrete blocks, a number of fish and macro-invertebrates taxa inhabited the restoration site, and their number increased in three-folds when compared to adjacent natural reefs as the transplanted corals continued to become bigger (personal observation). Consistent with other authors (Fadli *et al.,* 2012; Williams *et al*., 2019; Fox *et al*., 2019), our findings suggest that simple concrete block structures provide a stable substrate and habitat that can increase coral cover and fish abundance and successfully restore a coral-rubble dominated reef.

About one hectare of reef area was rehabilitated by deployment of more than 60 concrete blocks. The blocks were assembled to form about 10 pyramid clusters and distributed on different rubble patches within the CCA, with an estimated cost of US \$ 72300 ha^{-1} (US\$ 7.2 m^{-2}). Costs reported from comparable restoration methods that used artificial reef structures to restore unconsolidated substrate reef range from \$ 25/m^2 to \$35-277/m^2 (Edwards *et al*., 2010; Williams *et al.*, 2019). The bulk of the expenses is usually attributed to the materials used to consolidate the rubble dominated fields or attaching coral fragments such as marine cement, epoxy glues and rental boats and the labour cost of restoration experts. In this community-based restoration project, locally available and affordable materials such as sand, normal cement and coral boulders were used to construct concrete blocks. Additionally, the high labour intensity required throughout the project, associated with labour cost for construction of mid-water nurseries, artificial concrete structures, periodic cleaning and maintenance of nursery corals and transplanted corals, and boats for access to site, were provided freely (in-kind labour) by participating community members, contributed to reducing reef rehabilitation cost by 20%.

Similar to another reef restoration projects, involving the local community in restoration has also been found to be effective and advantageous (Trialfhianty & Suadi, 2017). However, no study in the WIO region has demonstrated that community-participation in coral reef restoration activities can work and have practical advantages in the long-term such as increased stewardship in environmental restoration as it involves building community awareness activities. Additionally, extensive community involvement in the whole project starting from the initial stages of restoration work not only reduces the cost of operation itself, but training in the basics of coral biology and the need for restoration in poor degraded reefs has advanced the development of coral restoration project among local community members that allows the community to understand the importance of taking care of their reef resources (Russ & Alcala, 1999). This in turn may then encourage a sense of ownership and responsibility that may ensure long-term stewardship and interest in protecting local coral habitats (Cruz *et al*., 2014). As an immediate benefit of involving the local community in restoration they have also been showcasing their restoration sites to tourists, thus making an additional benefit that could develop into an alternative livelihood of local residents (Cadiz & Calumpong, 2002). On average, there has been an 80-100% increase in their weekly income, from

US 60 to US 220 for the BMU during high tourism seasons (unpublished data).

In conclusion, this community-based restoration project presented here is successful in terms of survival, over 70% after one year, and improved local abundance of fish around artificial reefs deployed. This initial results are promising and resource managers, conservationists and local community are encouraged to adopt this approach to rehabilitate degraded reefs with similar conditions. Additionally, this project suggests that local community can be practically involved in restoration of their degraded reefs when provided with training and simple guiding steps on restoration as it encourages their participation and stewardship (as also observed in relate studies, e.g., Juinio-Men˜ez *et al.,* 2012) and when intervention uses low-tech method that is affordable to the community (Cruz *et al.,* 2014). The present study, being a pilot in implementation, raises many opportunities for reef researchers and local communities to continue partnering and develop this technique further, as well as monitoring in order to understand fully the benefits and/or impacts of this reef restoration approach.

Acknowledgements

The authors would like to thank the anonymous reviewers for their helpful contributions to the final manuscript.

References

Abelson A (2006) Artificial reefs vs coral transplantation as restoration tools for mitigating coral reef deterioration: Benefits, concerns, and proposed guidelines. *Bulletin of Marine Science*, *78*(1), 151–159.

Cadiz PL, Calumpong, HP (2002) Analysis of revenues from ecotourism in Apo Island, Negros Oriental, Philippines. *Proceedings of the Ninth International Coral Reef Symposium, Bali, 23-27 October 2000, 2*, 771–774.

Clark S, Edwards AJ (1995) Coral transplantation as an aid to reef rehabilitation: Evaluation of a case study in the Maldive Islands. *Coral Reefs*, *14*(4), 201–213. https://doi.org/10.1007/BF00334342

Cruz DW dela Villanueva RD, Baria MVB (2014) Community-based, low-tech method of restoring a lost thicket of Acropora corals. *ICES Journal of Marine Science*, *71*(7), 1866–1875.

Edwards A, Guest J, Rinkevich B, Omori M, Iwao K, Levy G, Shaish L (2010) Evaluating costs of restoration. In A. Edwards (Ed.), *Reef Rehabilitation manual*. Coral Reef Targeted Research & Capacity Building for Management Program. 172pp. Retrieved from https://ccres.net/images/uploads/publications/3/reef_rehabilitation_manual_web.pdf

Edwards, AJ (Ed.) (2010) *Reef Rehabilitation Manual.* The Coral Reef Targeted Research & Capacity Building for Management Program. Retrieved from https://ccres.net/images/uploads/publications/3/reef_rehabilitation_manual_web.pdf

Edwards AJ, Gomez ED (2007) *Reef Restoration Concepts and Guidelines: Making sensible management choices in the face of uncertainty*. Capacity Building for Management Programme/Coral Reef Targeted Research. Retrieved from http://www.vliz.be/en/imis?refid=109714

Epstein N, Bak RPM, Rinkevich, B (2001) Strategies for Gardening Denuded Coral Reef Areas: The Applicability of Using Different Types of Coral Material for Reef Restoration. *Restoration Ecology*, 9(4), 432–442. [https://doi.org/10.1046/j.1526-100X.2001.94012.x]

Fadli N, Campbell SJ, Ferguson K, Keyse J, Rudi E, Riedel A., Baird A. H. (2012) The role of habitat creation in coral reef conservation: A case study from Aceh, Indonesia. *Oryx*, *46*(4), 501–507.

Forrester GE, O'Connell-Rodwell C, Baily P, Forrester LM, Giovannini S, Harmon L, Karis R, Krumholz J, Rodwell T, Jarecki, L (2011)

Evaluating Methods for Transplanting Endangered Elkhorn Corals in the Virgin Islands. *Restoration Ecology*, *19*(3), 299–306. [https://doi.org/10.1111/j.1526-100X.2010.00664.x]

Fox HE, Harris JL, Darling ES, Ahmadia GN, Razak TB (2019) Rebuilding coral reefs: Success (and failure) 16 years after low-cost, low-tech restoration. *Restoration Ecology*, *27*(4), 862–869.

Grimsditch G, Tamelander J, Mwaura J, Zavagli M, Takata Y, Gomez T (2016) Coral Recruitment and Coral Reef Resilience on Pemba Island, Tanzania. In S Diop, P Scheren, JF Machiwa (Eds.), *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean* (pp. 277–287). Springer.

Gudka M, Obura D, Mwaura J, Porter S, Yahya S, Mabwa R. (Eds.) (2018) *Impact of the 3rd global coral bleaching event on the Western Indian Ocean in 2016*. Global Coral Reef Monitoring Network (GCRMN)/ Indian Ocean Commission.

Hoegh-Guldberg O, Poloczanska ES, Skirving W, Dove S (2017) Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers in Marine Science*, *4*(158), 1–20. [https://doi.org/10.3389/fmars.2017.00158]

Johnson M, Lustic C, Bartels E, Baums I, Gilliam D, Larson E, Lirman D, Miller M, Nedimyer, K, Schopmeyer S (2011) Caribbean Acropora Restoration Guide: Best Practices for Propagation and Population Enhancement. *Marine & Environmental Sciences Faculty Reports*, 1–64.

Juinio-Meñez MA, Paña MA, de Peralta GM, Catbagan TO, Olavides RDD, Edullantes CMA, Rodriguez BDD (2012) Establishment and management of communal sandfish (Holothuria scabra) sea ranching in the Philippines. In : CA Hair, TD Pickering, DJ Mills (Eds.), *Asia–Pacific tropical sea cucumber aquaculture: Proceedings of an international symposium held in Noumea, New Caledonia, 15–17 February 2011*. The Australian Centre for International Agricultural Research (ACIAR). pp 121–127

Lindahl ULF, Öhman MC, Schelten CK (2001). The 1997/1998 mass mortality of corals: Effects on fish communities on a Tanzanian coral reef. *Marine Pollution Bulletin*, *42*(2), 127–131.

Mangi SC, Roberts CM (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. *Marine Pollution Bulletin*, *52*(12), 1646–1660.

Marzinelli EM, Zagal CJ, Chapman, MG, Underwood AJ (2009) Do modified habitats have direct or indirect effects on epifauna? *Ecology*, *90*(10), 2948–2955. [https://doi.org/10.1890/08-1893.1]

Mbije NE, Spanier E, & Rinkevich B (2010). Testing the first phase of the 'gardening concept'as an applicable tool in restoring denuded reefs in Tanzania. *Ecological Engineering*, *36*(5), 713–721.

McClanahan TR, Marnane MJ, Cinner JE, Kiene WE (2006) A comparison of marine protected areas and alternative approaches to coral-reef management. *Current Biology*, *16*(14), 1408–1413.

McClanahan T, Sheppard R, Obura DO (Eds.) (2000) *Coral Reefs of the Indian Ocean: Their Ecology and Conservation*. Oxford University Press.

McDonald T, Gann G, Jonson J, Dixon K (2016) *International standards for the practice of ecological restoration–including principles and key concepts*. Society for Ecological Restoration. Retrieved from https://cieem.net/wp-content/uploads/2019/07/SER_Standards_2016.pdf

Murage L, Mwaura JM (2015) Wasini community rallied to secure its future: People and the Environment. *WIOMSA* Magazine no. *7*.

Mwaura JM (2013) Participatory assessment of the effects of community conserved areas (CCAs) on coral reefs to support enhanced adaptive management practices. *Kenya Marine and Fisheries Research Institute.*, *2*, 1–12.

Mwaura J, Umezawa Y, Nakamura T, Kamau J (2017) Evidence of chronic anthropogenic nutrient within coastal lagoon reefs adjacent to urban and tourism centers, Kenya: A stable isotope approach. *Marine Pollution Bulletin*, *119*(2), 74–86.

Ng CSL, Toh TC, Chou LM (2016) Coral restoration in Singapore's sediment-challenged sea. *Regional Studies in Marine Science*, *8*. [https://doi.org/10.1016/j.rsma.2016.05.005]

Obura D, Gudka M, Rabi FA, Gian SB, Bigot L, Bijoux J, Freed S, Maharavo J, Mwaura J, Porter, S, Sola E, Wickel J, Yahya S, Ahamada S (Eds.) (2017). *Coral reef status report for the Western Indian Ocean (2017)*. Global Coral Reef Monitoring Network (GCRMN)/International Coral Reef Initiative (ICRI). Retrieved from http://www.nairobiconvention.org/CHM%20Documents/Reports/Coral%20Reef%20Report%202017.pdf

Obura D, Smits M, Chaudhry T, McPhillips, J., Beal D, Astier, C. (2017) *Reviving the Western Indian Ocean economy: Actions for a sustainable future*. WWF International.

Precht WF (Ed.). (2019) *Coral Reef Restoration Handbook* (1st edition). CRC Press.

Raymundo LJ, Maypa AP, Gomez, ED, 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*(7), 1009–1019.

Rinkevich B (2006) The coral gardening concept and the use of underwater nurseries: Lessons learned from silvics and silviculture. In W Precht (Ed.), *Coral reef restoration handbook*. Taylor & Francis. pp 291–301. Retrieved from http://www.vliz.be/en/imis?module=ref&refid=100600&printversion=1&dropIMIStitle=1

Rinkevich B (2005) Conservation of Coral Reefs through Active Restoration Measures: Recent Approaches and Last Decade Progress. *Environmental Science & Technology*, *39*(12), 4333–4342. [https://doi.org/10.1021/es0482583]

Russ GR, Alcala, AC (1999) Management histories of Sumilon and Apo Marine Reserves, Philippines, and their influence on national marine resource policy. *Coral Reefs*, *18*(4), 307–319.

Shafir S, Edwards A, Rinkevich B, Bongiorni L, Levy G, Shaish L (2010) Constructing and managing nurseries for asexual rearing of corals. In A. Edwards (Ed.), *Reef Rehabilitation Manual.* The Coral Reef Targeted Research & Capacity Building for Management Program. pp. 49–72. Retrieved from https://www.academia.edu/25026644/Constructing_and_managing_nurseries_for_asexual_rearing_of_corals

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

Sheppard CR (2003) Predicted recurrences of mass coral mortality in the Indian Ocean. *Nature*, *425*(6955), 294–297.

Soong K, Chen T (2003) Coral Transplantation: Regeneration and Growth of Acropora Fragments in a Nursery. *Restoration Ecology*, *11*(1), 62–71. [https://doi.org/10.1046/j.1526-100X.2003.00100.x]

Spurgeon JP, Lindahl U (2000) Economics of coral reef restoration. In HS Cesar (Ed.), *Col-*

lected Essays on the Economics of Coral Reefs. CORDIO, Department for Biology and Environmental Sciences. 242 pp

Suding KN (2011) Toward an era of restoration in ecology: Successes, failures, and opportunities ahead. *Annual Review of Ecology, Evolution, and Systematics*, *42*(1), 465–487.

Tamelander J, Obura D (2002) Coral Reef Degradation in the Indian Ocean: Status Report 2002. In O. Lindén, D. Souter, D Wilhelmsson, & D Obura (Eds.) *Coral reef rehabilitation: Feasibility, benefits and need*. CORDIO East Africa. 276 pp. Retrieved from http://www.cordio.org/reports/cordio_status_report_2002-2.pdf#page=257

Trialfhianty TI, Suadi (2017) The role of the community in supporting coral reef restoration in Pemuteran, Bali, Indonesia. *Journal of Coastal Conservation*, *21*(6), 873–882. [https://doi.org/10.1007/s11852-017-0553-1]

Wilkinson C (Ed.) (2008) *Status of Coral Reefs of the World: 2008*. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000179217

Williams SL, Sur C, Janetski N, Hollarsmith JA, Rapi S, Barron L, Heatwole SJ, Yusuf AM, Yusuf S, Jompa J (2019) Large-scale coral reef rehabilitation after blast fishing in Indonesia. *Restoration Ecology*, *27*(2), 447–456.

Young C, Schopmeyer S, Lirman D (2012) A Review of Reef Restoration and Coral Propagation Using the Threatened Genus Acropora in the Caribbean and Western Atlantic. *Bulletin of Marine Science*, *88*(4), 1075–1098. [https://doi.org/10.5343/bms.2011.1143]