Volume 6, Issue No.1

KENYA Aquatica

A Scientific Journal of Kenya Marine and Fisheries Research Institute

KMFRI

KENYA Aquatica

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Kenya Marine and Fisheries Research Institute

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 Chanage 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

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.

Contents

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).

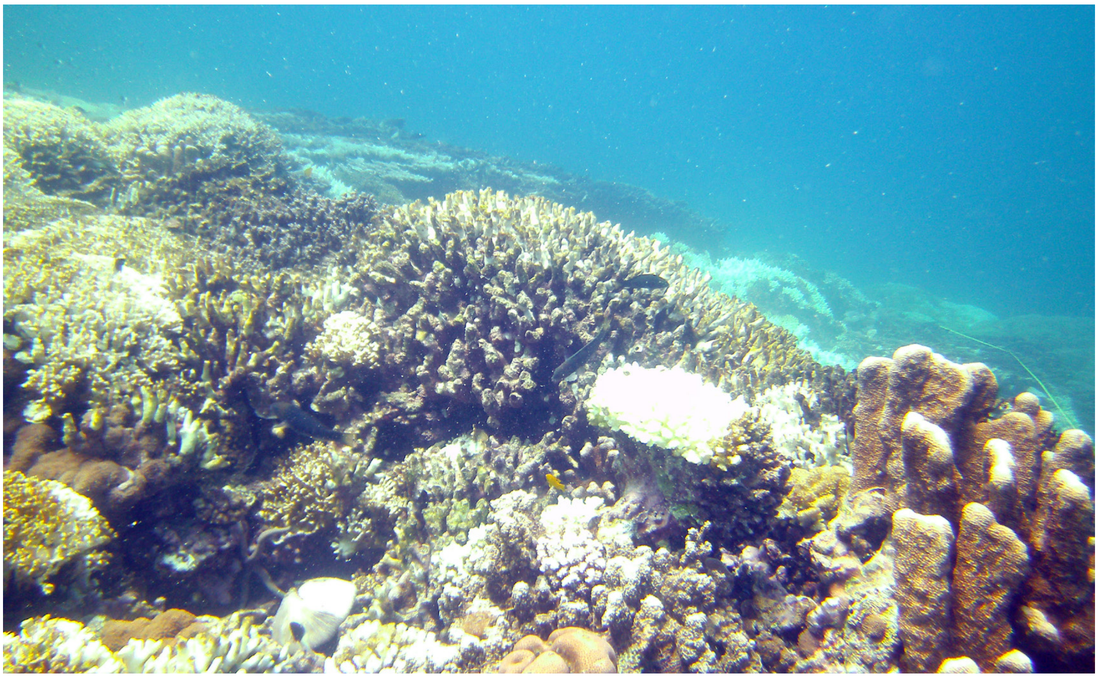

Fig. 1. An image of coral reef impacted by bleaching episodes in 2016. During this event, many reef corals bleached and died, resulting to loss of habitats that are critical for supporting fisheries and tourism sectors. Credit: Jelvas Mwaura.

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.

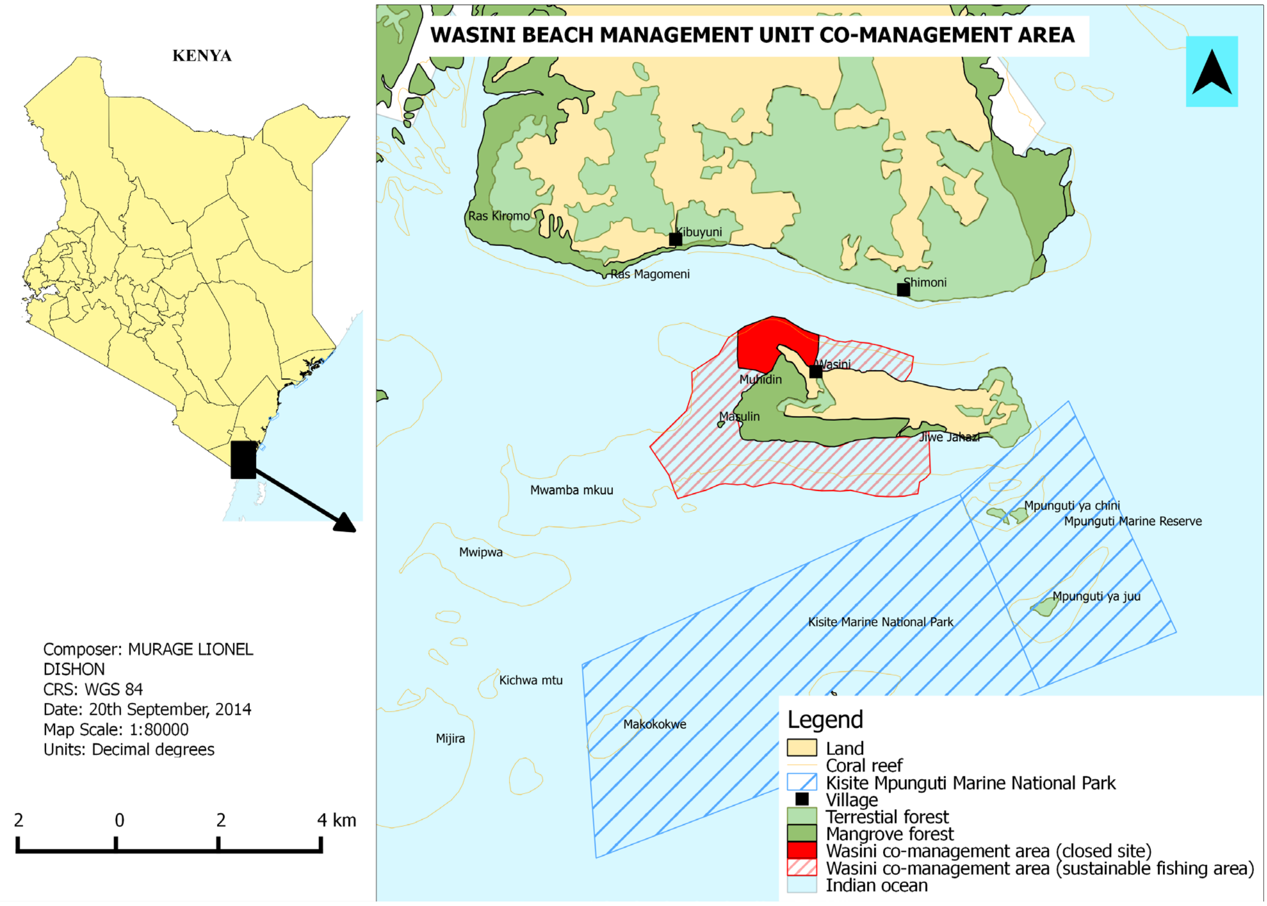

Fig. 2. Map of the community conservation area in Wasini Island, Southern coast of Kenya; where reef rehabilitation was undertaken in 2013.

ι) ***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.

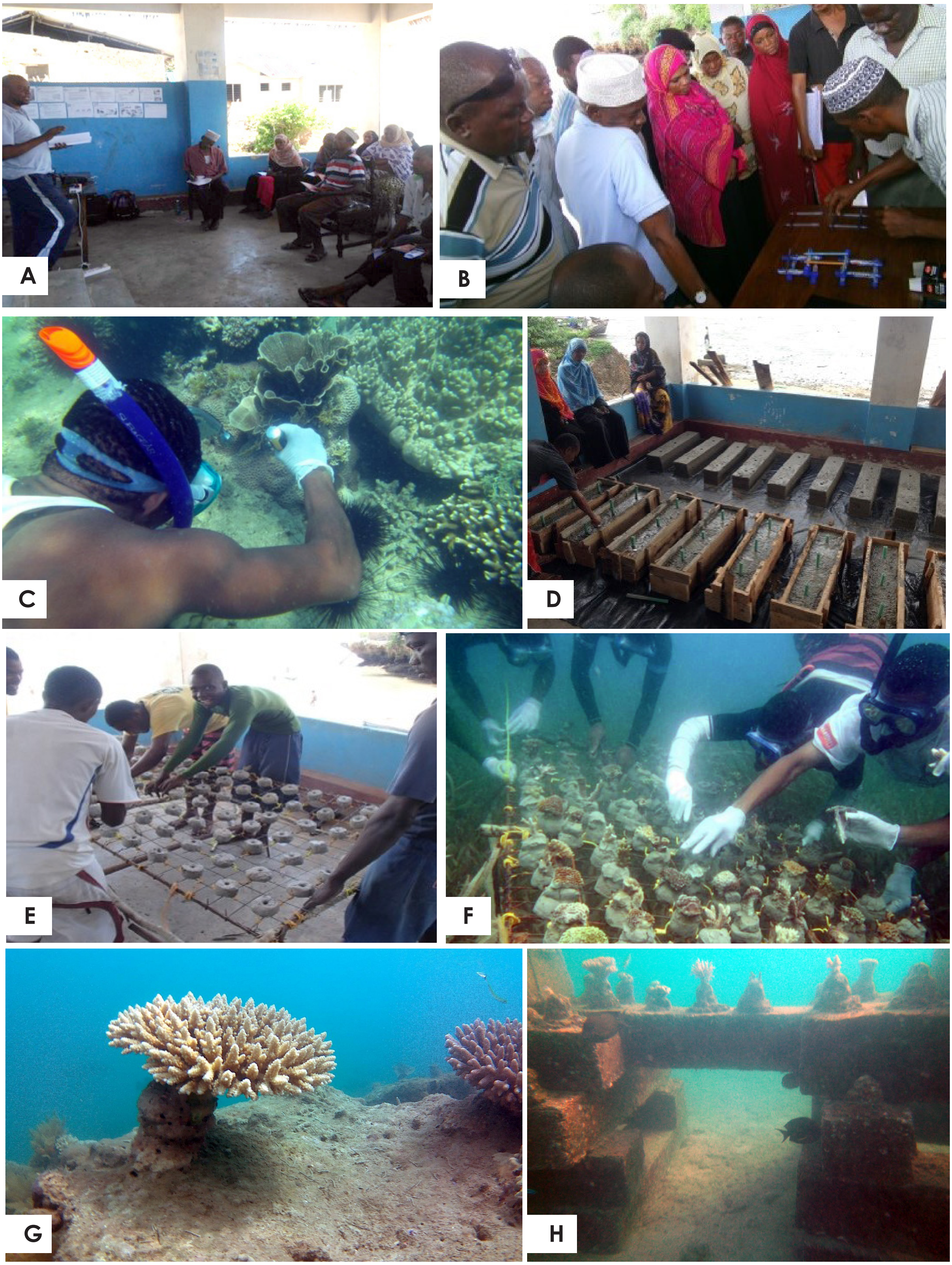

Fig 3. A) Awareness raising among local community members and reef managers, fisheries staff, B) participatory designing and construction of table nursery and concrete blocks, C) Collection of coral fragments, D. Construction of concrete blocks and cement discs, E. Construction of table mid-water nurseries, 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.

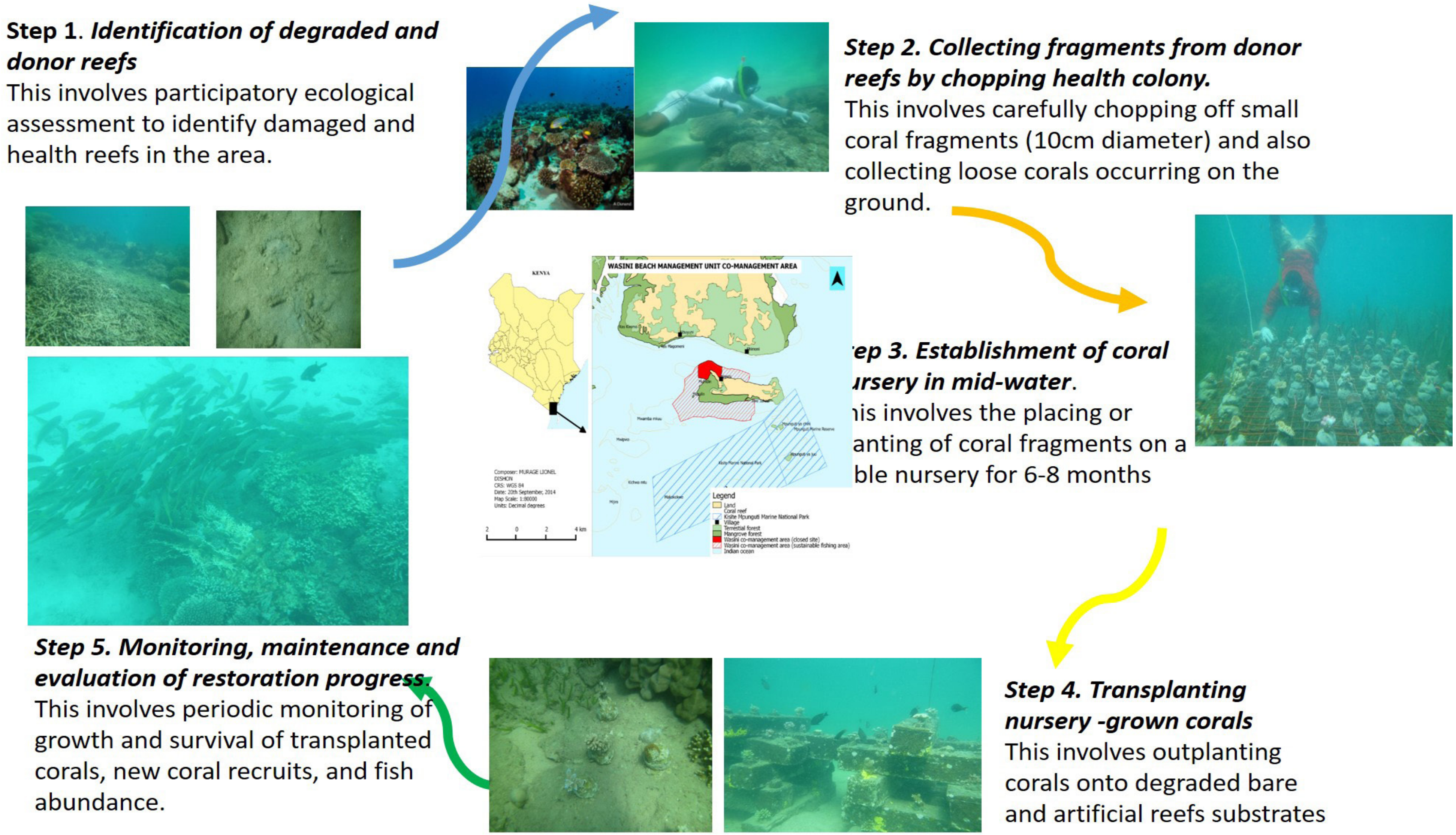

Fig. 4. A schematic diagram showing 5 important steps of the adapted community-based restoration protocol.

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*, *Lobophyllia*, *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

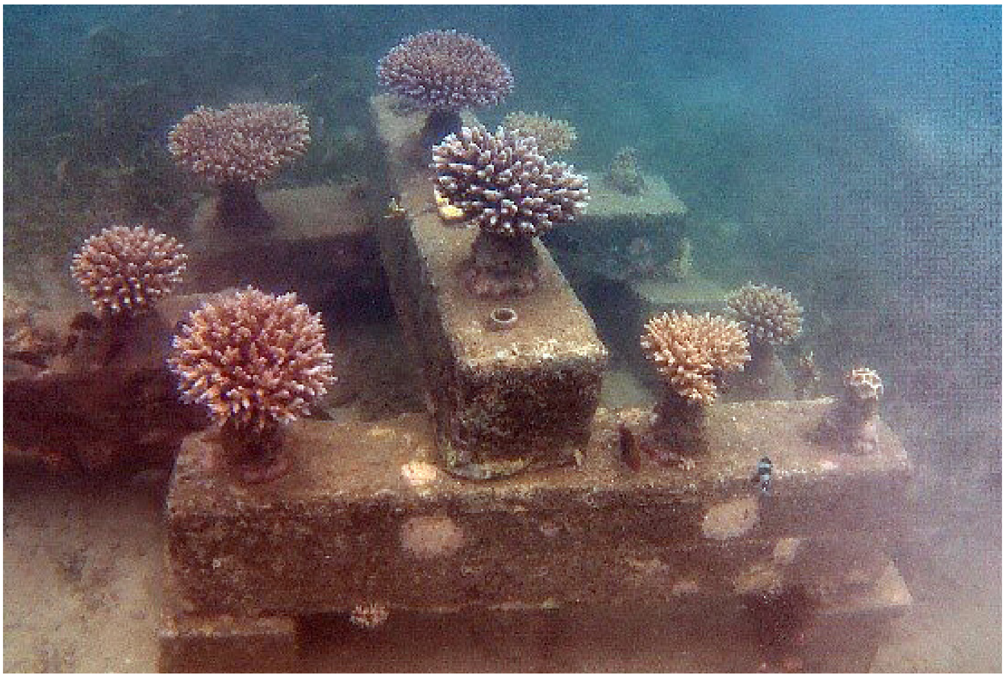

Plate 1. View of artificial reef structure at rehabilitated site upon which corals have been transplanted after one year.

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.

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Kenya Aquatica Journal. Vol. 6, No. 1, pp.17-31 , 2021

The Socioeconomic Impacts of Coral Reef Rehabilitation: Coastal Community Perspectives from Wasini in the South Coast Of Kenya

Faith K. Kimanga*, Jacob Ochiewo, Edward Waiyaki, Fridah Munyi, Jelvas Mwaura and Nicholas Karani

Kenya Marine and Fisheries Research Institute,

P.O Box 81651-80100, Mombasa, Kenya

* Corresponding author: faithkimanga7@gmail.com

Abstract

Coral reefs are highly diverse and productive ecosystems that serve many functions to coastal communities around the globe. In the coast of Kenya, corals are important as a source of livelihood and contribute in various ways to oceanic production, tourism, recreation and coastal protection. The subsistence and commercial use of coral reef resources in Kenya has persisted for centuries, resulting to increasing pressure from anthropogenic stress. Activities that have caused this stress along the coastline continue to be: destructive fishing methods, coral and sand mining for construction, pollution, and tourism. The socioeconomic impact of rehabilitated coral reef in Wasini Island was assessed in 2018 following successful rehabilitation undertaken in 2011. Purposive sampling was done in the villages of Wasini Island and Kijiweni. Data was collected by direct observation, semi-structured questionnaires and focus group discussions. Data analysis involved computation of descriptive statistics and content analysis. The findings show that the coral restoration efforts on Wasini Island generated significant benefits to the local residents and the environment. Majority of the respondents (55%) had primary level education thus able to read and write. The average weekly household income from all traditional sources combined was 623 Kenya Shillings (USD 6) higher than average weekly household income prior to coral rehabilitation thus showing the importance of the intervention. Benefits identified from coral rehabilitation included increased availability of fish (30%), increased income (18%), increased tourist attraction (17%), improved community welfare (14%), improved marine environment (5%), and creation of habitat for fish (3%). In addition, the initiative has promoted social integration among local residents. In a noticeable departure from past practices, where gender roles were clearly defined and strictly adhered to, the coral rehabilitation project has led to increased community cohesion as both men and women, young and old equally incorporated into rehabilitation activities.

Key words: Socioeconomic impact, rehabilitated coral, coastal communities, social integration

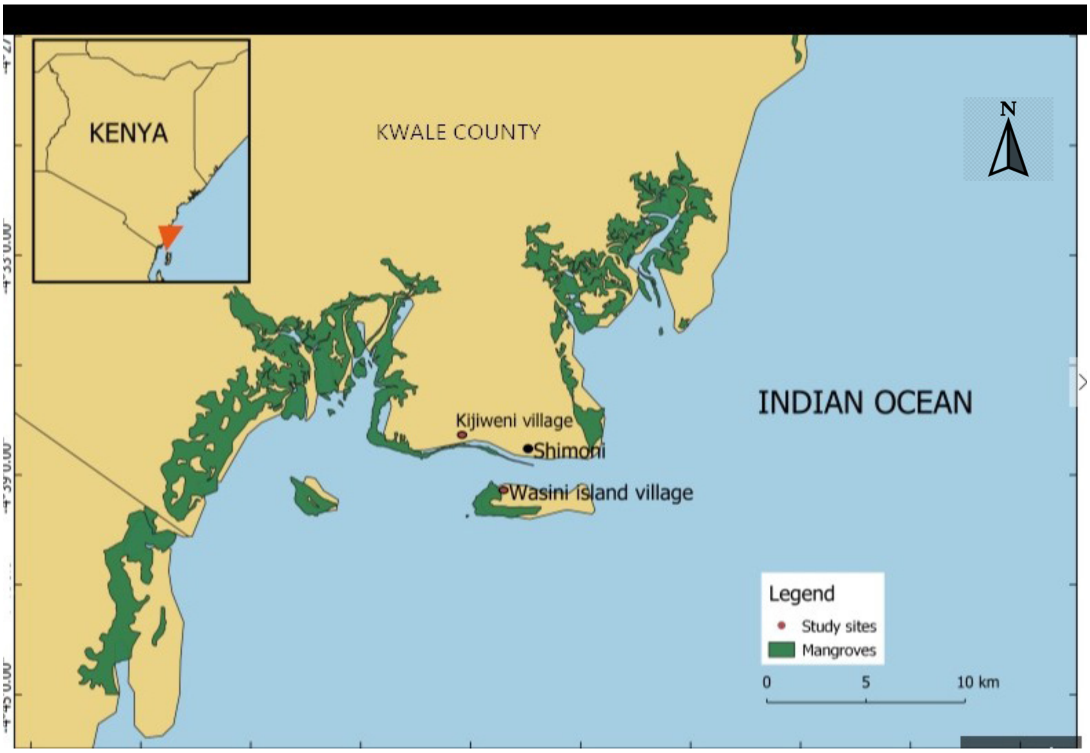
Introduction

Globally coral reefs are among the most productive ecosystems with rich biodiversity (Roberts *et al*., 2002; Serageldin, 1998; Birkeland, 1997). They provide ecosystem goods and services that support the livelihoods and income of the people who reside within the coastal zones (Wilkinson, 1999; Burke *et al*., 2002). Some of the key ecosystem goods and services provided by coral reef ecosystems to the local communities include subsistence and commercial fisheries, shoreline protection (Whittingham *et al*., 2003; Cinner, *et al*., 2012) and tourism attractions. The goods and services provided by the coral reefs support food security, subsistence and commercial needs and economies of many developing countries (Pendleton, *et al*., 2016), and are necessary for health and sustainable development (Jenkins *et al.*, 1988). The two common reef based economic activities are fisheries and tourism with the latter being heavily dependent on coral reef as the main tourist attraction (Cesar, 2000). The touristic value of coral reefs stems from their intrinsic beauty that attracts tourists to enjoy their aesthetic values.

At present coral reefs are exposed to increasing pressures from human activities and anthropogenic stresses (Burke *et al.*, 2012), and there is no virgin coral in the world (Hodgson, 1999). Additionally, more research findings indicate that the species richness and biodiversity contained in reef ecosystems may not regenerate once destroyed (Rogers, 2013). Thus, the conservation and restoration intervention of damaged coral reefs has become of major interest among many resource managers and conservationists.

The coral reef restoration is a sustainable use practice and is gaining recognition due to the declining reefs (Darling & Côté, 2018; De'ath *et al*., 2012). In Kenya there is approximately 630 square kilometers of coral reef coverage, and of which 91% is under threats (ICRI, 2018). A recent reef monitoring results shows that over 70% of coral reefs are in a poor status (0-25% live coral cover) and less than 5% are in good condition (Obura *et al*., 2017). In 2014, a community-based coral restoration was initiated at Wasini in the south coast of Kenya by KMFRI with funding from the World Bank funded Kenya Coastal Development Project (KCDP). The KCDP provided financial support, with the aim of building climate change resilience and adaptive capacity of vulnerable communities, through rehabilitation of the degraded coral reefs in the south coast. Previously, low-tech coral farming was successfully tested by KMFRI scientists and was shown to be a viable method for restoration of degraded reefs, albeit at small-scale level (Murage & Mwaura, 2015). After successfully implementing the coral reef rehabilitation, carried out together with the local community group, it became necessary to assess its socioeconomic impacts with focus on the local community, which these efforts are meant to serve. Understanding these social, economic, and cultural dimensions of restoration efforts can motivate conservationists tailor more initiatives towards communities they are intended to benefit (Lundquist & Granek, 2005).

The general objective of the study was to assess the socioeconomic impacts of coral reef rehabilitation at Wasini. The specific objectives were to: establish baseline information on the status of Wasini Island's rehabilitated coral; determine the income changes in households associated with the impact coral rehabilitation; assess perceptions on coral rehabilitation (CR) and management and to identify coral use patterns around Wasini Island.



Material and Methods

Site Description

The study was conducted at Wasini village, Wasini island and Kijiweni village in the mainland in Kwale County, south coast of Kenya (Fig. 1).

Fig. 1. Map of the Kenya coastline showing Wasini Island village

Wasini village hosted the coral rehabilitation project. During the study, an area of 1ha had been rehabilitated with corals. The coral rehabilitation project site falls within the Wasini Community Conservation Area (CCA) which is managed as a community initiative by the Wasini Island Beach Management Unit (BMU). Wasini community has an approximate population of 2080 people with 220 households. Kijiweni which was also covered by this study has about 500 people with 40 households. Both Wasini and Kijiweni villages are characterized by high dependence on the coral reef resources and mangroves for both subsistence and livelihoods. Over 60% of the households in both villages have for many generations largely been depending on exploitation of these habitats for their livelihoods through artisanal fisheries and tourism (Murage & Mwaura, 2015). However, just like in many areas, these shallow coral reefs have been affected by multiple anthropogenic stressors, including land-based pollution, overfishing and climate change (Mwaura, 2013; Obura, *et al.,* 2017). In Particular, the Wasini nearshore reefs showed poor reef condition being characterized by low coral cover (<10%), high algae cover (> 45) and low density of fish (<20 individual per 250m^2) (compared to healthy reefs of coral cover (>35%) and fish abundance (>204/250m^2)) Muthiga (2009).

To rehabilitate these degraded reefs, local communities and other stakeholders were involved in transplanting more 800 coral fragments within the Wasini conservation area. After 3-4 years, the reef restoration has brought benefits to the community by increasing fish abundance and improving the environment for tourist activities (Plate 1).

Plate 1: Tourist boarding a boat from Wasini

The deployment of artificial reef structures and subsequent attaching of corals has created a new habitat for fish breeding, enhancing fish populations by adding shelter and breeding grounds (unpublished). One remarkable observation is that these rehabilitated sites (Plate 2) has become a major attraction for tourists through diving and snorkeling, thereby creating an alternative source of income for Wasini village. On average, there has been 80% increase in their monthly income, from US60 to US 220 for the BMU during high tourist season (pers comm).

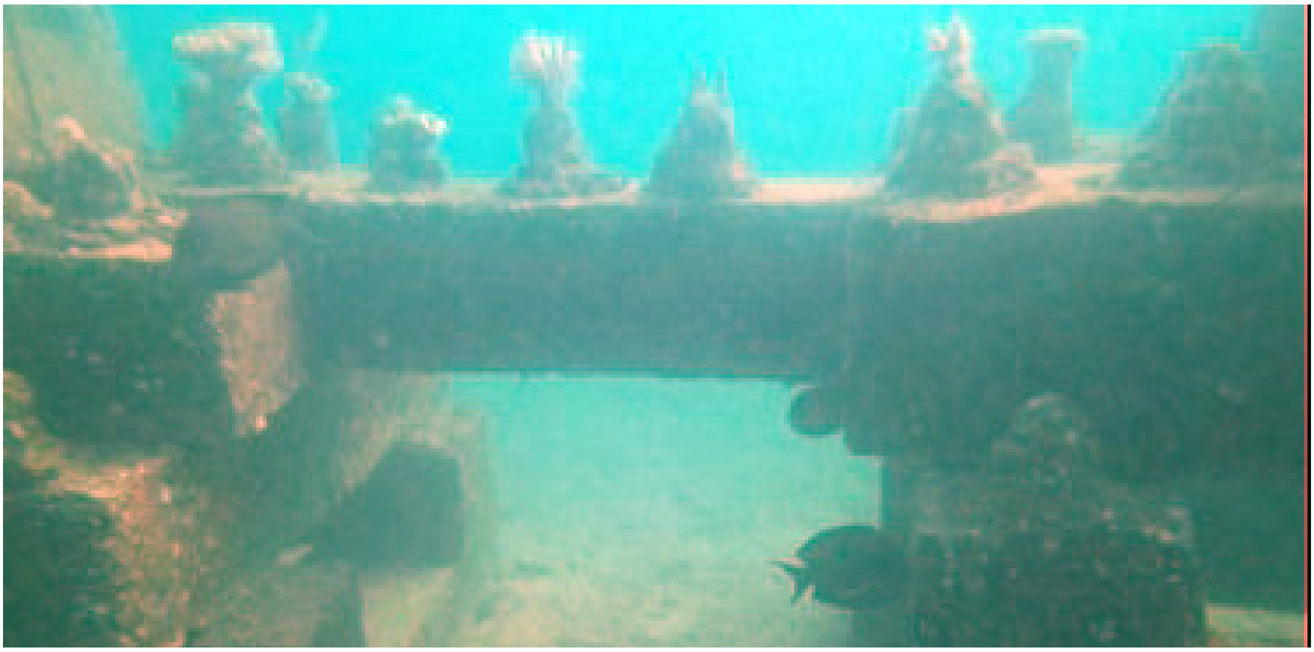


Plate 2: **Picture of rehabilitated site in Wasini conservation area, showing new corals and fishes**

Sample Size and Data Collection

This study was carried out over a period of 3 months between May and August 2018. The study targeted residents of Wasini village that hosted the coral rehabilitation project and residents of Kijiweni village who conducted activities close to the coral rehabilitation site. Random sampling was used to select a representative sample from the two villages. The sample consisted of people who were involved in rehabilitation project and the general community to minimize biased responses. A sample size of 60 was chosen and a response rate of 78% was obtained. Data collection involved collection of primary, desktop and literature review on the topic of study. Primary data collection involved use of mixed method approach to generate information from the respondents. This included questionnaire survey, direct observation and focus group discussions (Creswell & Clark, 2017). A questionnaire survey was conducted with the households. Semi-structured questionnaire consisting of both closed and open-ended questions was used and it consisted of four sections namely: (1) Demographic characteristics, (2) Involvement and impacts of coral rehabilitation, (3) Awareness and knowledge of importance of coral rehabilitation, (4) Attitudes towards the rehabilitated coral reef management strategies and enforcement. The questionnaire was administered in Kiswahili which was the most preferred language in the area. The variables were measured at both nominal and ordinal scales. The nominal scale presented the respondents with two unordered options, while a 5-point ordinal scale was used by the respondents to rate the degree of agreement to some statements concerning coral rehabilitation. For example, when gauging the level of awareness and knowledge of the importance of coral rehabilitation.

Focus Group discussions were used to provide additional details and validate the questionnaire responses regarding the impacts of coral rehabilitation on the community (McLafferty, 2004) The focus group consisted of 6 members of the Beach Management Unit as recommended by Bunce *et al*. (2000); Macdonald and Headlam (2008) who were responsible for the management of the coral rehabilitation project. Direct Observation was applied to keenly watch the various coral related activities taking place in the area and photographs of key events or activities were taken.

Data Analysis:

A mix of both qualitative and quantitative data was compiled, cleaned and validated (Grech, 2018). Data analysis involved computation of descriptive statistics particularly measures of central tendency which include means, mode and frequencies. Further, content analysis was conducted on qualitative data to generate main themes using the Statistical Package for the Social Sciences (SPSS) version 22.

Results and Discussions

Demographic Characteristics

The socio demographic characteristics of the respondents from the coral rehabilitation project included age, gender, education level and occupation. The respondents had a mean age of 44 ±16.38 years with the youngest being 20 years old and the oldest being 73 years old. The respondents therefore fell in the economically active middle age category as indicated in Ochiewo *et al.*, (2010) which is associated with a zealous population that is capable of participating effectively in the coral rehabilitation activities which are labor intensive. Majority (62%) of the respondents were male while 38% were female, both of whom had resided in their particular villages for an average of 39±17.9 years. About 55% of the respondents had attained complete primary education while 13% had incomplete secondary education, 9% had no education, 6% had incomplete primary, 6% had Madrassa and 2% had tertiary education. This finding shows that the respondents generally had low levels of education, although most of them could read and write, and could also participate effectively in coral rehabilitation and related activities. In terms of livelihood diversification, 36% of the respondents who were male engaged in fishing and fish trade, while women were involved in small scale business (Table 1).

Table 1: Socio-demographic characteristics of the coral rehabilitation respondents in Wasini Island and Kijiweni village

Age	***Number***	***Proportions (%)***	
Range	53		
Mean	44 ± 16		
Mode	65		
Gender			
Males	29	62	
Females	18	38	
Education level			
None		9	
Madrassa		6	
Incomplete primary		6	
Complete primary		55	
Incomplete secondary		13	
Complete secondary		9	
Tertiary		2	
Occupation		Males	Females
Builder		2	0
Commercial diver		2	0
Cooks		0	4
Craftsman		2	0
Farmer		2	0
Fish traders		4	2
Fisherman		32	0
Livestock rearing		4	0
Madrassa instructor		2	0
Retired		2	2
Small scale business		2	26
Teaching		2	2
Tourist operator		2	0

The importance of fishing and fishing related activities confirmed the finding of Whittingham *et al*. (2003) that many coastal residents consider fishing as a way of life and an integral part of their social and economic existence. The emergence of small business as a major occupation for the women also confirms the finding by Ochiewo (2004), that in the south coast of Kenya, women were involved in fish marketing and distribution which are essentially categorized as small scale businesses.

Household income and income derived from coral rehabilitation

The study revealed that the mean household income was KES3,517 per week which translates to KES14,068 per month. The household income included income from coral rehabilitation related activities and income from other sources including fishing related economic activities and small business. Income derived from the coral rehabilitation, ranged from KES750 to KES11,250 per week with a mean of KES2,894 per week. Comparison between the average household income and the average income derived from coral rehabilitation revealed that the average household income from all sources was KES623 higher than the weekly average income from coral rehabilitation activities as presented in the Table 2. This implies that coral rehabilitation has contributed significantly to the diversification of livelihoods in the community. The earnings may get the participating households out of poverty and have them live above the international poverty line which currently stands at US$1.90 per day, at US$1 equivalent to KES100.

Table 2: Comparisons between the household income and the coral rehabilitation income derived

House Hold income (KES) weekly		Income derived from Coral rehabilitation (KES) weekly
Mean	3517	2894
Mode	2500	2500
Range	34800	10500
Minimum	200	750
Maximum	35000	11250
N	43	16

An analysis of level of involvement in activities related to corals in the study sites revealed that coral rehabilitation provides livelihood to about 50% of the respondents' and their family members who are engaged in related activities such as coral rehabilitation activities, working in tourist establishments, fishing, and security guards with most income being obtained from fisheries and tourism activities. About 46% of the respondents had participated in coral rehabilitation activities of whom 61% were females while 36% were males. There was a clear division of labour especially in some activities for instance patrolling to provide security to the coral gardens was a male responsibility. Participation involved engagement at different levels by the community members (Fig.2).

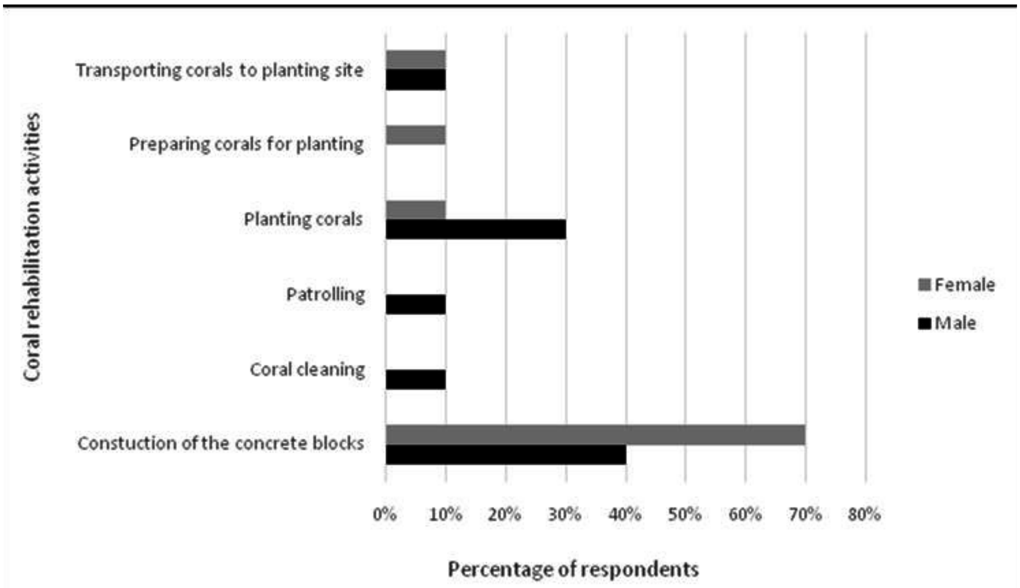


Fig. 2: Participation in the coral activities across gender

The people who were directly involved in coral rehabilitation consisted of an average of 19 men and 10 women, Indeed, the participation of women in the activity implies gender equity unlike the past women were highly discriminated against due to cultural stereotypes with respect to sea-based activities. Majority (72%) stated that the Wasini BMU was in charge of the initiative while 19% implied that KMFRI, 4% SDF, and 4% KWS were in charge respectively. The successful coral rehabilitation has stirred a rise of ecotourism in the Wasini Island. Consequently, the need for up-scaling coral rehabilitation has been identified by various stakeholders as a means of poverty alleviation. Currently, 42% of the Kenyan population lives below the international poverty line (UNDP, 2018) with the coast being equally affected by poverty.

The coral rehabilitation and use patterns

The study established that the beneficiaries of the coral rehabilitation project included the entire Wasini community (82%), and particular groups in the community such as fishermen (5%), fish traders (2%), boat operators (2%) and 9% of the respondents did not know who the beneficiaries were since they did not directly interact with this resource (Fig. 3).

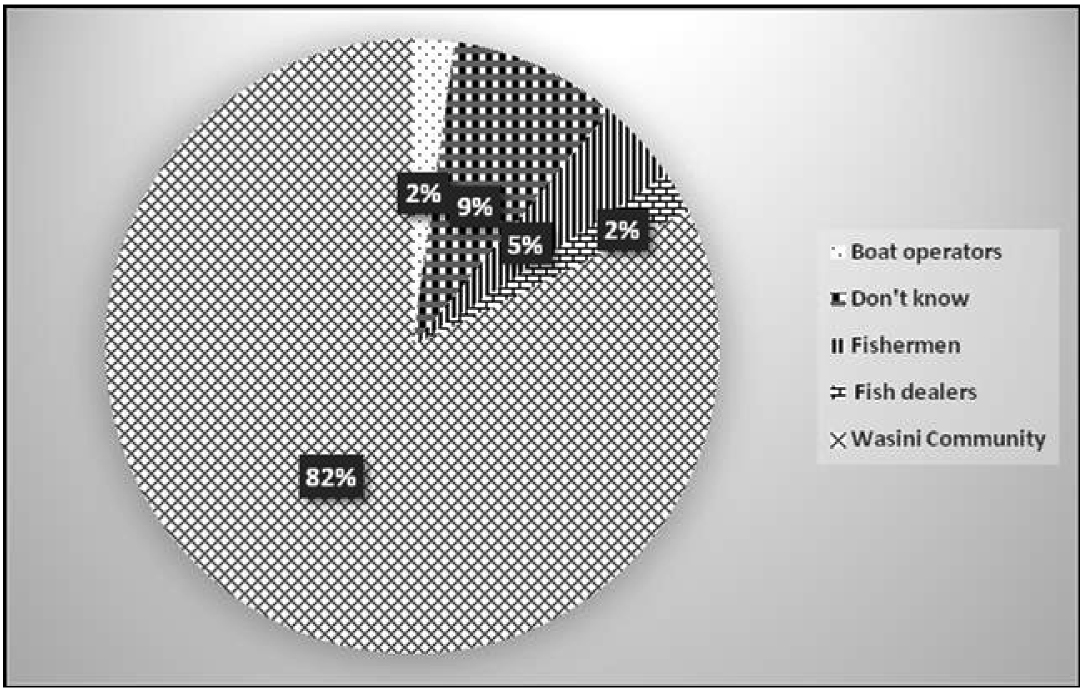


Fig. 3: Perceived beneficiaries of the coral rehabilitation initiative

With regards to the respondents' satisfaction with the coral rehabilitation project, 68% of the respondents were satisfied, 24% were not satisfied while 8% had mixed feelings. Among the respondents who were not satisfied were some fishermen who felt that their right to fish in the rehabilitated area which was part of their fishing ground had been interfered with through protection of the rehabilitated corals.

Nevertheless, both targeted and untargeted beneficiaries identified various benefits that were derived from the coral rehabilitation project. This included: increased availability of fish (30%), increased income (18%), tourist attraction with the rehabilitated corals becoming a popular tourist attraction generating much valued income which has benefitted both the Wasini BMU and the island residents (17%), improved community welfare (13%), improved marine environment through creation of a beautiful and clean coral zone (5%), provision of habitat for fish (3%), recreational benefits for the local community members (1%) while 13% felt that there were no benefits (Fig.4; Plate 2).

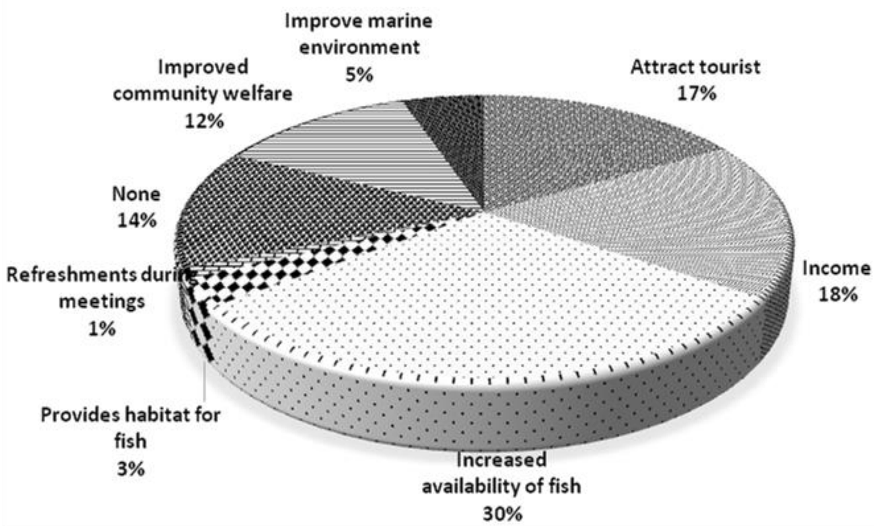


Fig. 4: Coral rehabilitation perceived benefits distribution in the community

This confirms the earlier identified use patterns as indicated in Hoorweg and Muthiga (2009). Participatory involvement in these initiative by respondents is also consistent with the observation by Hernández-Delgado *et al*. (2018) that low-tech coral farming and reef rehabilitation have become important community-based coral reef management tools in the Caribbean. These measures have also been used with relative success to recover depleted fish assemblages and also to provide multiple new microhabitats for fish and invertebrate species. It also confirms the observation by Blue Economy Community Solutions that corals that are rehabilitated in this way have also proved to be an enhanced attraction for visitors and recreationists (UNDP, 2018).

Awareness and knowledge of the importance of coral rehabilitation was measured on a 5 point Likert scale indicating a mean awareness index of 3.9 (79%). Awareness is therefore seen to be increased especially where the community's major source of livelihood is positively impacted and in this case we find that most of the respondents' awareness was inclined towards attraction of fish and tourists by the coral rehabilitation initiative (Fig. 5).

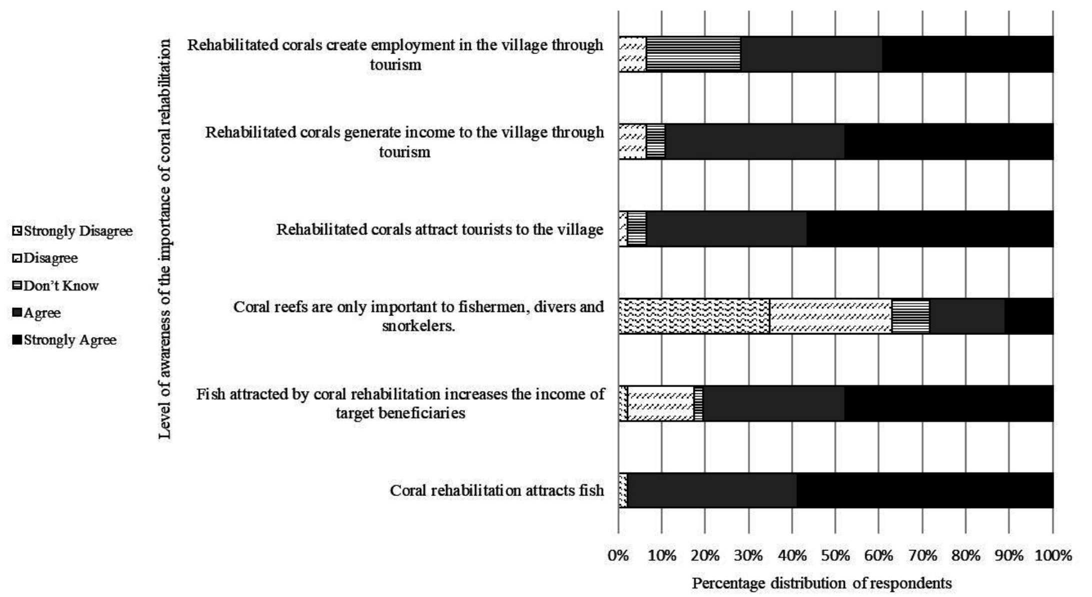


Fig. 5: Level of awareness of the importance of coral rehabilitation

Fisheries production has increased in both Wasini and Kijiweni, as has the diversity of fish species attributed to the coral restoration which has increased fish stocks by functioning as a breeding ground. The restoration of damaged sites with hard coral has created new habitat and increased structural complexity, enhancing fish populations through adding shelter and breeding spots. Vibrant fish stocks of Community Conserved Areas (CCA) can act as sources of new fish recruits which ultimately provide socio-economic benefits to local populations. Further, the process of community coral reef restoration and the learning opportunities involved therein contribute to developing a sense of resource stewardship over the coral resource. Creating healthy corals outside the Kisite Marine Park will also release pressure from this frequently visited Marine Park and ecotourism will form an additional sustainable source of income for local residents (Zacarias & Loyola, 2017).

Social integration was reported to have been enhanced in the villages due to the existence of the coral rehabilitation project. About 86% of the respondents reported that the coral rehabilitation project has increased the community cohesion. The coral rehabilitation has further promoted a culture of conservation of nature (38%), increased participation of women in development projects (10%) and livelihood diversity (3%), However, a small section of the community felt that the coral rehabilitation has created undesired interactions between women and men (5%) and fishermen denied access to fish in the site (4%) (Fig.6).

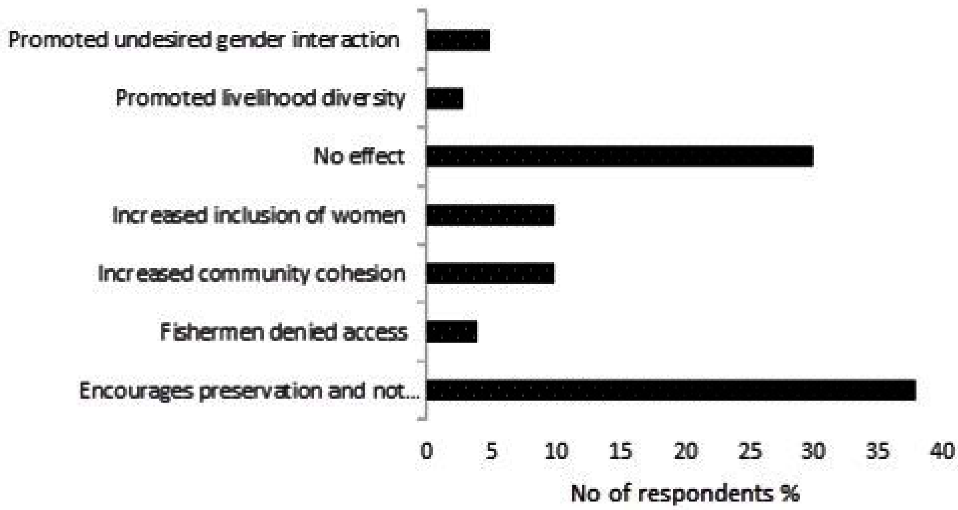


Fig. 6: ***Impacts of coral rehabilitation on culture***

Regarding the distribution of economic benefits among the target beneficiaries, 57% of the respondents indicated that the earnings from the coral rehabilitation project were used for funding community welfare activities, 24% did not know how it was distributed and 19% felt that the benefits were not distributed fairly. Additionally, the funds collected from the project by the Wasini Beach Management Unit was used to pay school fees for the bright but needy students, purchase of medicines for the dispensary and also pay local religious leaders. 72% of the respondents were therefore willing to start individually owned coral rehabilitation projects while the rest still had reservations.

Threats to the rehabilitated corals

Despite the endless efforts that have been put, corals still continue to face both natural and anthropogenic pressures. Within this locality, various threats to the rehabilitated corals were identified to include use of destructive fishing that was identified by 35.7% of the respondents followed by adverse sea condition (21.4%), marine pollution (14.3%), anchoring boats on the coral zone (14.3%), harvesting corals for house construction (7.1%), trampling over by those engaged in fishing activities (5.7%) and inconsistency in conservation efforts (1.4%) (Fig. 7).

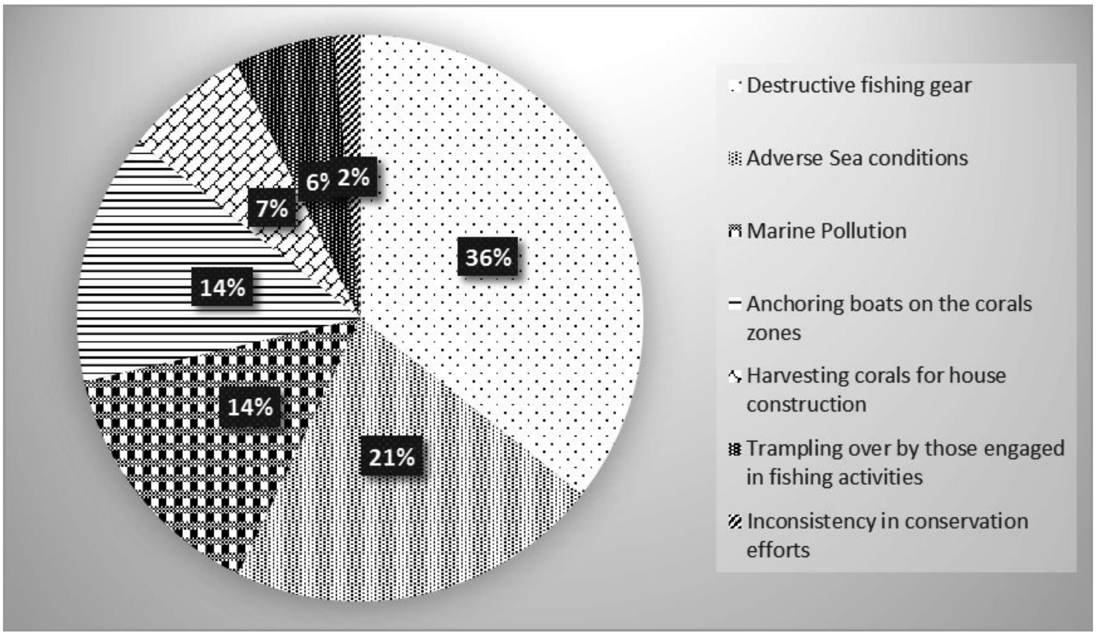


Fig. 7: Threats to the rehabilitated corals

Several measures have been adopted to curb the threats namely having by-laws relating to restriction of fishing in the coral rehabilitation area, avoidance of dumping of waste into the sea, patrol and provision of security in the area, clearly demarcating the coral zone, sensitization on the effects of destructive gears, monthly cleaning of the marine environment, and re-routing of fishermen. Majority of the respondents (62%) were aware of fishing restriction around the coral zone while only 2% of the respondents were aware of the visitation fees, regular security patrols, and forced re-planting of corals around the rehabilitated zone (Fig. 8).

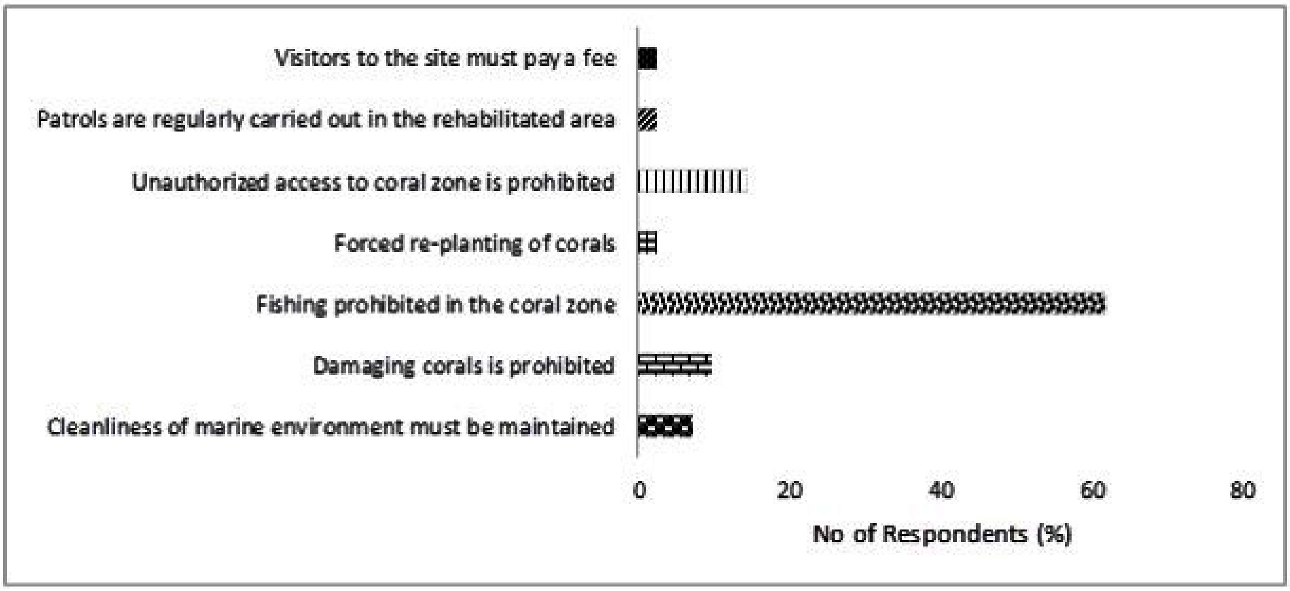


Fig. 8: Mechanisms put in place to curb the coral rehabilitation threats

Implementation of these mechanisms was understood by a majority (78.0%) of the respondents to be the responsibility of the Wasini Beach Management Unit while 16.0 % were of the opinion that the County Department of fisheries in collaboration with the Marine Police were responsible while 6.0% stated that the Kenya Wildlife Service was mandated with this responsibility. Management of such common use marine resources requires that all key stakeholders be involved. Concerning rules governing coral rehabilitation, 76.1% of the respondents agreed that there were rules prohibiting coral damage, fishing in the coral zone and unauthorized access to coral zone. However, 15.2% of the respondents stated that there were no rules while 8.7% were not aware of any rules. In order to safeguard their relentless efforts, the respondents gave several recommendations to aid in the rehabilitation. These included: controlling access to corals, BMU to be continuously involved in surveillance of the corals, equitable sharing of revenues accrued from coral rehabilitation among the community, need to expand coral rehabilitation zones, increase community sensitization on coral rehabilitation, fishermen to be empowered to venture in to offshore fishing and banning all destructive fishing gears within the area.

Conclusion and Recommendations

Conclusion

Coral rehabilitation at Wasini Island has contributed significantly to the diversification of livelihoods for the community and enhanced social integration. The success of the mitigation initiative is associated with the creation of the welfare fund under the rehabilitation project, which is used to pay school fees for the needy and bright children from the village, purchasing drugs for the local dispensary and paying salaries to the teachers who are hired by the parents-teachers association, and supporting religious teachers. It has had overall positive implications to the local community's economic, environmental and social well-being through the generation of tourism revenues, increased fishing incomes and enhanced food security.

Over 800 coral fragments were transplanted within the Wasini conservation area. After 3-4 years, the coral restoration has brought benefits to the community by increasing fish abundance and improving the environment for tourist activities. The deployment of artificial reef structures and subsequent attaching of corals has created a new habitat for fish breeding, enhancing fish populations by adding shelter and breeding grounds. These rehabilitated sites have become a major attraction for tourists through diving and snorkeling, thereby creating an alternative source of income for Wasini village, and has resulted in 80% increase in the local BMU's monthly income, from USD 60 to US D 220 during high tourist season. The coral rehabilitation has changed gender participation in sea-based activities by empowering more women to be involved in the coral rehabilitation project unlike in the past when women in Wasini Island were not involved in most sea-based activities.

In addition, the coral rehabilitation has resulted in increased availability of fish and tourist attraction with the rehabilitated corals becoming a popular tourist attraction thus changing the use pattern of the rehabilitated site. It has improved marine environment by creating a beautiful and clean coral zone, providing a habitat for fish, and enhancing recreational benefits for the local community members in tandem with use patterns identified by Hoorweg and Muthiga (2009).

Finally, the success of the coral restoration project has addressed poverty alleviation and food security which are key issues in the Kenya Government's development agenda. Food security has been addressed through increased fish production and increased income from tourism that have increased availability and access to food of good nutrition to the project beneficiaries.

Recommendations

Based on the foregoing conclusions, the following recommendations are advanced:

1) Up-scaling of coral rehabilitation to other areas in the coast of Kenya would contribute to an enhanced supply of fish in the region and alleviate the food insecurity experienced by the coastal population. Up-scaling coral rehabilitation will require building the capacity of local communities to equip them with techniques that are employed in coral restoration.
2) Sustainable management of corals, greater participation of users and multi-stakeholder involvement in the decision-making processes including policy formulation, should be promoted. This should involve increasing community sensitization on coral rehabilitation by conducting regular awareness and education activities amongst the coastal communities with respect to proper stewardship of the marine environment and ensuring strict monitoring and surveillance of the corals through regular patrols to prevent their damage. Inclusion is an essential factor if any community project such as coral rehabilitation is to succeed.
3) It is important to intensify awareness creation of the coral conservation initiative to the local communities as well as the other players in the marine sector so as to attract collective action on collective solutions at both the local and national level.

Acknowledgements

This study was supported by the government through the Kenya Marine and Fisheries Research Institute (KMFRI) Government (GoK) seed fund. We acknowledge every person who participated in enabling the success of the study, including the KMFRI Socio-economics team, the Wasini Beach Management Unit officials, the Wasini village chairman, Mr. Rashid Mohammed and Kijiweni Village chairman Mr. Khamisi Nasoro for their support during the survey. Additionally, we thank all the respondents for their willingness to participate in the study.

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Comparison between Drying Characteristics of Siganids in a Sand-Base Solar Tunnel Dryer and a Traditional Rack Dryer

Oduor-Odote, P.M [1], Shitanda D[2], Obiero[1] M,

[1*] Kenya Marine and Fisheries Research Institute, Box 81651-80100, Mombasa.

E mail: podote@gmail.com

[2]Jomo Kenya University of Agriculture & Technology, BEEDS, Box 62000, Nairobi

[1*] All correspondences

Abstract

Solar dryers are seldom used for fish drying at the Kenyan coast despite abundant sunshine. A sand base solar tunnel dryer was fabricated at Gazi in South Coast, Kenya. The dryer was then used to attempt drying Siganids and its effectiveness measured against that of a traditional rack dryer. The dryer was made using steel, timber, glass, wire-mesh, a solar system with two DC fans, UV treated polythene sheet, coconut fibre, sand and black paint. The net drying time of the fish was 30 hours and moisture loss was logarithmic. The starting fresh weight of the Siganids in the solar tunnel dryer was 350 ± 53.0g; by day-one, recorded weight was 165 ± 30.5g, by day-two the weight was 80g ± 17.4 representing a 77.14% loss and 60 ± 21.0g by day-three equivalent to 5.71%.

In the traditional rack, the starting fresh weight was 250 ± 50.6g which reduced to 70 ± 44.2g by day-two then to 60 ± 35.5g by day-three equivalent to 4% loss. Drying was discontinued when no further weight loss occurred. There was a significant difference ($p<0.05$) in weight and moisture loss between the solar tunnel dryer and the traditional rack ($p=0.0001$, $p=0.0038$) respectively. The rate of drying was faster in the solar tunnel dryer compared to the traditional drying rack ($p = 0.0134$). Humidity and temperature varied diversely during drying in the solar tunnel dryer with humidity reaching 22-28% while temperatures ranged from 60-69°C. In the traditional rack, humidity was constant during peak heat drying periods at 60-70% with temperatures of 30-33°C. Lower humidity and higher temperatures inside the solar tunnel dryer caused the faster drying rates. The fish in the solar tunnel dryer attained a final moisture content of 17.9%. No insect infestation was curtailed by design when using the solar tunnel dryer.

It is concluded that the solar tunnel dryer is more effective in drying fish than the traditional drying rack. There is no insect infestation during drying in the solar tunnel dryer and the fish is dried to a low moisture content in the solar tunnel dryer which is more suitable for longer storage. It recommended that fish processors at the beach start migrating to adopt solar drying technologies to reduce drying time, get fish that can be stored for a longer time due to lower moisture content.

Key words: Drying, Moisture, Humidity, Temperature

INTRODUCTION

Traditional fish preservation methods common in Kenya includes sun drying as can be seen by observing the bulk of fish sold in the markets. Drying is used to reduce as much as possible the water content from foods to prevent or inhibit microorganism growth and hence preserve the food. Also, this reduces the bulk weight of food for cheaper transport and storage. Very little fish is landed by artisanal fishermen at the Kenyan coast between the months of April to early October while November and March is characterized by a glut. During this glut, it is relatively difficult to process the excess harvest. The fishermen sell cheaply to middlemen with the rest going to waste (FAO, 2000). Some of the fish is laid on the ground, on sand occasionally covered with fishing nets or on rocks to dry (personal observation). The disadvantage of these natural outdoor drying methods is that the drying process is slow making it unhygienic, tedious because the fish has to be brought inside every time it rains and each evening to avoid dew and its consequences such as mould, dust contamination, insect infestation, and exposure to harm from human or animals. These result in very low-quality fish with limited market circulation hence low income (Mujaffar & Sankat, 2005; Sablani et al., 2003).

The improvement of the quality of cured fish through technological advances is an important intervention that aims to reduce post-harvest losses and to create a wider appeal for the cured fish market. With the abundance of sunlight in this region, improved drying methods can be introduced. Attempts to use improved drying technologies in Kenya have been carried out by Shitanda and Wanjala (2006) and Uluko et al., (2006). However, none has been tried on fish. The use of solar dryers provides one such method of improved drying (Rao et al, 1987; Curran & Trim, 1982). However, these methods have had challenges with air movement inside the dryers (Bala & Mondol, 2001). Drying proceeds efficiently when air is hot, dry and moving. These three factors are inter-related and it is important that each factor is correct so that, cold moving air or hot, wet moving air are both unsatisfactory. Bala and Mondol, (2001), Bala et al., (2005), Hossain et al., (2005) and Reza et al., (2009) have utilized improved dryers with forced air convection to dry various food products including fruits, cereals, grains, legumes, oil seeds, fish and spices. In this study, a sand base solar tunnel was constructed for use in drying Siganids which is one of the commonly landed, popular and abundant species in the South coast area (FAO, 2000; Kimani et al., 2018) When drying is carried out correctly, the nutritional quality, colour, flavour and texture of dehydrated foods are maintained.

The aim of this study was to compare the drying characteristics of Siganus sutor fish in a traditional rack dryer (TR) with a locally fabricated solar tunnel dryer (SD) in Gazi, south coast of Kenya.

METHODS

Solar Tunnel Dryer construction

The dryer was designed and fabricated at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in consultation with Kenya Marine and Fisheries Research Institute (KMFRI) with modifications according to Bala and Mondol (2001). This was a community-based project, and Gazi area of south coast of Kenya was selected. Gazi is set on a mangrove filled bay off the Mombasa-Lunga Lunga-road about 50km from Mombasa and lies 4°25', 39°30'E. It is in Kwale county, Coast region in Kenya. The major landing seasons are between October and March. The area was chosen because the community had identified with its implementation and was therefore easier to get locals to help run the solar tunnel dryer once installed.

Solar Collector

The solar collector was a tunnel 7m long, 2m wide and 0.4m above the ground. The tunnel height was 300mm. The maximum height at the center was 450mm above the collector base. The top outer cover was made from two layers of UV (Ultra Violet) treated polythene sheet of 500G (0.5mm). The base of the collector was made of a 2mm thick metal plate painted black for heat absorption and encased in a sand layer for refractory and heat storage purposes. Below the sand layer, a double insulation of 5mm thick wood followed by a 20mm thick coconut fibre layer was made. At the bottom a 2.5mm wooden layer was fitted. The collector was encased in a 0.5mm polythene layer. The sides of the collector were fabricated using 2mm thick metal plate painted black for heat absorption and lined by a 50mm thick coconut fibre layer for insulation. The outer surface of the collector wall was made of 25mm thick wooden layer painted black to absorb heat. To facilitate the entry of air into the collector a 2m by 0.6m galvanized sheet plenum mounted with a 40W DC fan was fixed onto the collector (Figure 1).

Drying Chamber

The drying chamber was a cabinet measuring 2m wide, 2m long and 1.4m high set at 0.5m above the ground. The maximum height of the dryer was 1.55m above the base of the cabinet. The sides of the dryer were made from 25mm thick plywood, which was lined with 0.05mm galvanized iron sheet for reflection and painted black on the outside for heat absorption. The base of the dryer cabinet was lined with 0.05mm aluminium sheet for heat reflection and ease of cleaning. A 5mm thick wooden layer, followed by a 50mm coconut fibre layer and finally a 2.5mm wooden layer for insulation encased the aluminium sheet. The roof of the drying cabinet was made from 4mm thick glass to allow for solar radiation into the cabinet and ease of inspection during the drying process.

Figure 1. View of designed tunnel dryer

The chamber had three shelf layers for holding twelve wire mesh trays measuring 1m by 1m and spaced 200mm apart with a maximum capacity of 200kg of fish. These were accessed from the side of the dryer cabinet via hinged doors, which could be opened wide to allow for sliding the trays in and out of the drying cabinet during loading or offloading. At the outlet of the dryer cabinet an exit plenum 2m wide by 1.4m wide fitted with a chimney 30mm in diameter and encased with a 40W DC fan was fitted to facilitate the removal of moist air from the drying chamber. The power supply system for the solar dryer was a photovoltaic system consisting of a 100W solar panel and a 100Ah deep cycle battery. This power system was used to power two 40W DC axial fans with a capacity of 0.46m3/h.

Drying of Siganids

A total of 240 fresh Siganids were purchased from the local fishermen in Gazi a day before solar drying in late October 2012. Only sound, wholesome fish free from adulteration and organoleptically detectable spoilage were subjected to further processing. The fish was sorted to obtain similar sizes where possible. The average weights were recorded after being descaled, de-gilled, split open and eviscerated. Thorough washing was done followed by salting at a salt:fish ratio of 1:10. Alternate layering of the fish and salt was done in a wooden trough with a salt layer applied at the bottom (on top of the wooden layer) and at the top of the final fish layer.

The fish was then stacked in the trough from early evening to the following for approximately 16 hours before drying. The fish was then washed to remove excess salt, transferred to chorkor oven trays, placed under a shade and held at an angle for 1 hour to drain. Half the fish was distributed randomly and laid in single layers on the drying trays in the drying chamber of the solar tunnel dryer (Figure 2). The other half was distributed randomly on the traditional rack lying next to the solar tunnel dryer and with the drying rack kept the same height as the drying rack of the solar tunnel dryer. Three random representative samples of fish each were taken from the solar tunnel dryer and traditional rack and weighed using a digital field balance (SALTPETERSK 2000-BLACK & DECKER, USA) to give the average starting weight of the fish before drying started. Every 2 hours during the day from 08.30 to 18.30 hours, drying temperature and humidity were measured inside the drying cabinet and on the traditional rack on the drying days. Temperature was measured using a normal mercury thermometer and humidity by a Humidity meter (HYGRO Haar-Synth, USA). Moisture loss was determined by randomly weighing the three representative pieces of fish from the solar tunnel dryer and dryer rack every 2 hours and returned. Two fish were sampled for moisture content determination every 2 hours during the drying period. They were wrapped in aluminum foil put in seal lock bags, labeled, placed on ice in ice boxes, taken to the laboratory in KMFRI and stored at -18°C till analysis.

Figure 2. Fish in the drying chamber laid in single layers

A complete drying period was between 8.30am to 6.30pm (10 hours) every day for three days giving a net drying period of 30 hours. Moisture content was determined by standard Helrich (1990) method, moisture loss as weight loss during drying after every 2 hours by getting the difference between starting weight and subsequent weight divided by starting weight and cumulative weight loss was weight loss every 2 hours as a percentage of fresh starting weight (Uluko et al., 2006). Insect infestation was assessed visually during drying.

DATA ANALYSIS

Rate of drying was compared using ANCOVA

RESULTS

Moisture Loss

The weight loss of Siganids in the solar tunnel dryer was from 350.0 ± 53.0g when fresh to 165.0± 30.5g (Figure 3) in day 1 to 80 ± 17.4g at the end of day-two. This was equivalent to 77.14%. In day-three the weight loss was from 80 ± 17.4g to 60 ± 21.0g which occurred between 20 to 22 hours (8.30am to 10.30am). This represented a weight loss of 5.71%. No further loss in weight was observed.

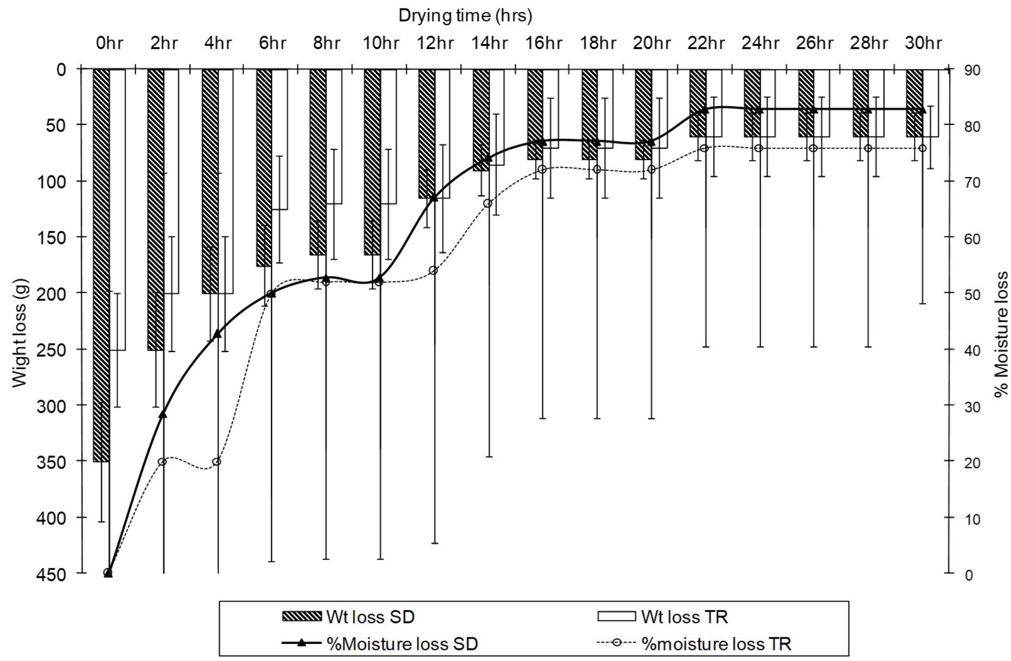

Figure 3. Drop in weight and % moisture loss of Siganids each day in Solar Tunnel Dryer (SD) and Traditional Rack (TR)

In the traditional rack, the weight loss was from 250 ± 50.6g to 70 ± 35.5g at the end of day 2 equivalent to 72%. In day-three the weight loss was from 70 ±42.4g to 60 ±35.5g that occurred between the 20 – 22 hours period (8.30am to 10.30am). This loss in weight was equivalent to 4%. The overall moisture loss was 82.85% for the fish dried in the solar tunnel dryer and 76% for the fish dried in the traditional rack at the end of the three day drying period (Figure 3). There was a significant difference in weight loss and moisture loss ($p<0.05$) between the Siganids dried in the solar tunnel dryer and the traditional rack ($p=0.0001$ and 0.0011) respectively.

The rate of drop in weight of the Siganids during the period was higher in the solar tunnel dryer compared to the traditional rack (Table 1, Figure 4). The weight losses observed indicated that most drying took place during the first 10 hours.

Table 1. Equations for drop in weight of Siganids over time

Day	Siganid in Solar Tunnel dryer	Siganid in Traditional rack
1	$y = -106.66 \ln x$	$y = -78.893 \ln x$
2	$y = -52.809 \ln x$	$y = -39.56 \ln x$
3	$y = -10^{-3} - 14 \ln x$	$y = -1.82 \ln x$

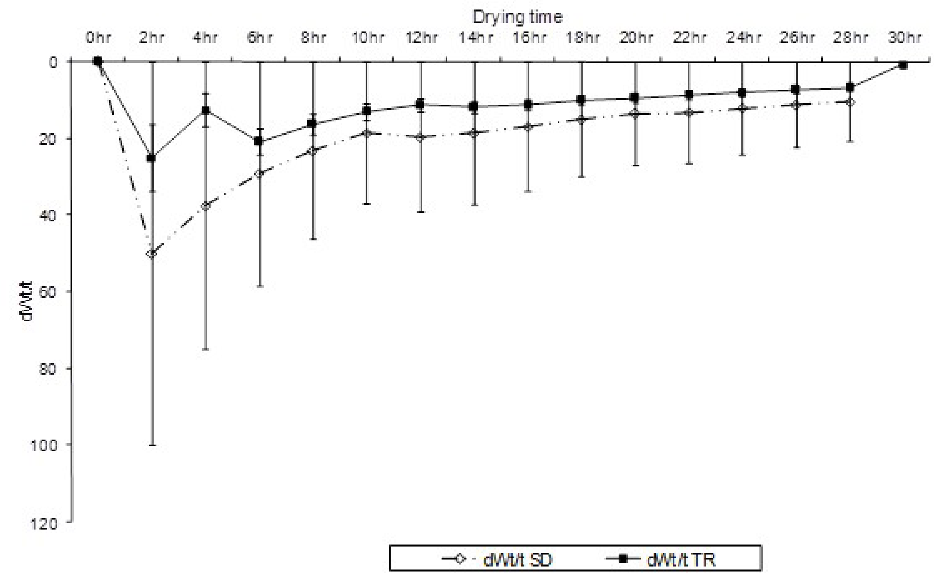

Figure 4. dWt/t of Siganids dried in the solar tunnel dryer (SD) and traditional rack (TR).

There was a statistically significant difference in drying rate (p = 0.0134) between the solar tunnel dryer and the traditional drying rack. Better drying rates were observed for the solar tunnel dryer. In day 1, humidity was 48% (Figure 5) at the start of the drying in the solar tunnel dryer (0 hours) and reduced to 23% between 2 and 6 hours equivalent to 10.30 hours and 14.30 hours (considered peak heat or drying times) and then increased as the evening approached to 80% at 18.30 hours.

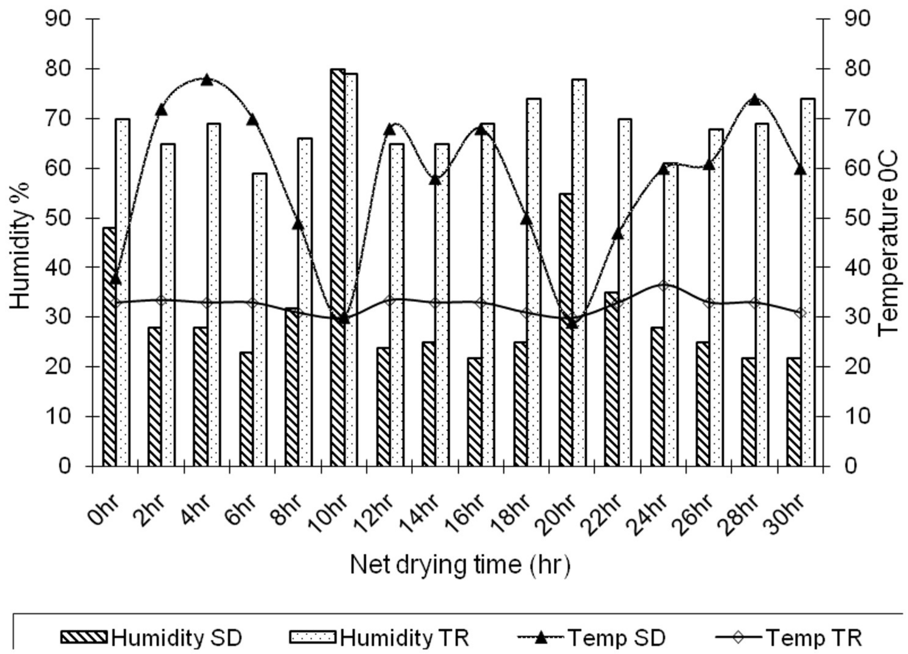

Figure 5 Humidity & Temperature in Solar Tunnel Dryer (SD) & Traditional Rack (TR)

Temperatures followed opposite trends. The temperatures increased from 38°C at the start of drying to a peak of 72°C between 2 and 6 hours drying period equivalent to 10.30 hours and 14.30 hours and finally dropped in the evening to 30°C. The temperature was considered rather high and could initiate cooking. The temperature was however controlled as the day progressed and in subsequent days. In the traditional rack, humidity in day-one was 70% (Figure 5) at the start of drying in the morning (0 hours) and ranged between 59% and 65% during peak drying periods of 10.30 hours and 14.30 hours (2 to 6 hours) and later increased to 79% towards the evening. In day-two, the humidity in the solar tunnel dryer followed the same pattern as in day-one with values of 22-24% being recorded between 10.30 hours to 14.30 hours (14 to 18 hours period). Temperature was more or less the same but this time the range was between 60-69°C during the peak heat periods. On day-two (12 to 20 hours period) in the traditional rack, the humidity was mainly between 65% - 69% during the peak heat period (14 to 18 hours period). The initial humidity was 75% at the start of drying in the morning and 78% by evening. The temperatures were between 30 to 34°C during the drying period. On day-three; the humidity in the solar tunnel dryer was low throughout with values of 22-28% being recorded during peak heat periods. The weather conditions on this day fluctuated unusually. Temperature kept rising most of the day and was between 48 to 70°C in the solar tunnel dryer. However effective drying or moisture loss was not quite evident during the third day. In the traditional rack the humidity was also rather high on this day averaging about 70%. Effective drying was not evident and average temperatures of 32-33°C were recorded.

The initial moisture content in fresh Siganids was 73.9% on a wet weight basis. This dropped to 17.9% ± 0.77 at the end of the three days in the solar tunnel dryer (Figure 6).

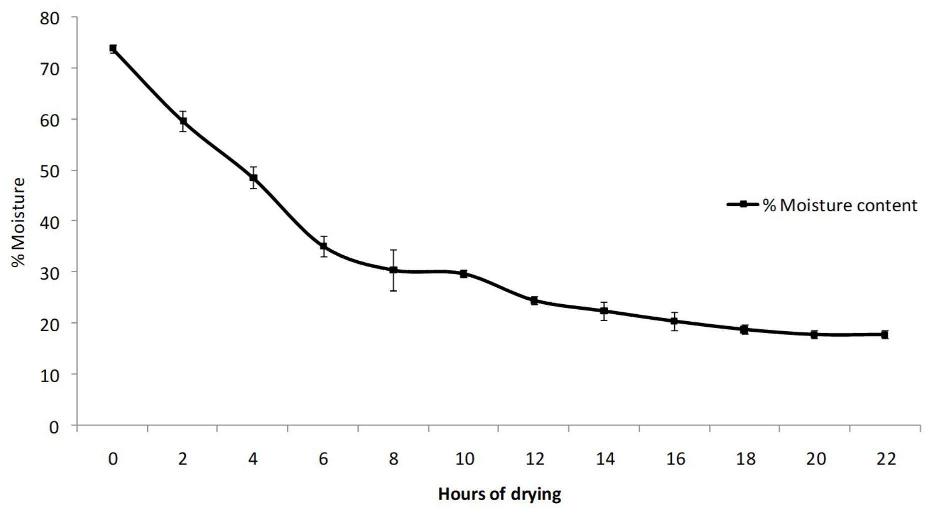

Figure 6. Moisture content (%) of Siganid during drying in solar tunnel dryer.

DISCUSSION

The starting weights of fish in the traditional rack were smaller and by inference thinner than those in the solar tunnel dryer. Thinner or smaller fish would normally dry faster than bigger or thicker ones. The surface area to volume ratio of smaller fish is normally higher resulting in faster drying rates (Mujaffar & Sankat, 2006). Work with shark fillets of various thicknesses showed that the thinner fillets lost moisture faster than the thicker ones (Mujaffar & Sankat, 2005). In this study the fish in the solar tunnel dryer showed more moisture loss despite their size. The factors that varied greatly and could be attributed to drying were temperature and humidity. The lower the humidity the faster the rate of drying (Mujaffar & Sankat, 2006). Dryers that give better drying rates have lower humidity and higher temperatures inside the drying units (Sablani et al., 2003). This trend was conclusively demonstrated using the solar tunnel dryer. The peak heat periods were also recorded as the peak drying periods, between 10.30 hours and 14 30 hours, humidity and temperature varied inversely during drying. It is postulated that higher temperatures maintained inside the solar tunnel dryer as a result of insulation on the collector, subsequent transfer of the heated air by forced convection over the fish coupled with direct radiation into the cabinet dryer and low humidity were responsible for the faster drying rate of the fish. During the drying period on the traditional rack, ambient temperature and humidity did not vary greatly. The daily temperatures were 30 - 33°C. Such temperatures are however not ideal for drying unless aided by another factor. Shark fillets dried at 30°C in an oven without air movement spoilt and discarded after 16 hours (Mujaffar & Sankat, 2005). Humidity was high under the ambient temperature conditions ranging from 60 to 79% mostly and could not have played a significant role. The reason for the relatively fast drying in the traditional open rack was attributed to the strong winds at the beach. The rack was located by the sea where wind speeds and value is quite strong. Although wind alone may result to in surface drying, it may not have much effect in internal water content. The rapid drying rate could also be due to a function of the air currents passing freely over and below the fish owing to the raised rack (Chamberlin & Titili, 2001). During drying, the moisture loss decreased with drying time meaning that the Siganids suffered greater moisture loss at the initial stage of drying. Such observations have been made by Mujaffar and Sankat, (2006), (Sablani et al., 2003). Moisture content is affected by drying time according to Sablani et al. (2003). Fish contains up to 80% water. When moisture is reduced to 25% wet basis, contaminating agents cannot survive and autolytic activity is greatly reduced (Bala & Mondol, 2001). However, to prevent mould growth during storage moisture must be reduced to 15% (Bala & Mondol, 2001). A report by Sankat and Mujaffar (2004) indicates that moisture contents of 20-40% for dry salted sun dried fish are acceptable. In this study the final moisture content attained for the Siganids was 17.9% after drying for three days in the solar tunnel dryer.

Unfortunately, insect larvae and insect infestation are a common occurrence in the fish dried using the traditional open rack method. This renders the fish unattractive leading to rejection by community members and loss of revenue. The solar dried fish which had no signs of insect infestation were therefore more attractive and acceptable to the community. The lack of infestation was attributed to the higher temperatures in the solar tunnel dryer during the drying process and the enclosed drying cabinet. Results from other studies have also yielded similar results (Bala & Mondol, 2001; Sankat & Mujaffar, 2004; Panduro et al., 2004; Mujaffar & Sankat, 2006; Kituu et al, 2008).

CONCLUSIONS

This study concludes that the sand base solar tunnel dryer provided a good alternative initiative for drying fish. The drying time of three days was also relatively short. The final moisture content of 17.9% was within the suitable range for dried fish storage. Humidity and temperature played a key role in the drying process. Insect attacks seen during drying in the traditional rack negatively affect the community members' perception of dried fish consumption.

RECOMMENDATIONS

The use of solar dryers to be encouraged by policy makers in the fishery industry due to the shorter drying times, improved fish quality and longer storage achievable due to the lower moisture content achieved

ACKNOWLEDGEMENT

We would like to acknowledge Western Indian Ocean Marine Science Association (WIOMSA) and Lighthouse Foundation of Germany through EEIU (K), for providing funds to conduct this research. The Director of KMFRI and the research team comprising S. Tunje, B. Okeyo, C. Odoli, B. Ohowa and I. Mukolwe are acknowledged for their inputs at various stages in the realization of this research.

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Comparative Drying Performance of Mackerel (*Rastrelliger kanagurta*) in a Solar Tunnel Dryer and an Open-air Raised Drying Rack

***Oduor-Odote P.M.[1], Shitanda D.[2], Kituu G.[2], Obiero M.[1], Ruwa R.K[1]**

[1] Kenya Marine and Fisheries Research Institute, Box 81651, Mombasa. Tel. 254 723809252

[2] Jomo Kenya University of Agriculture & Technology, BEEDS, Box 62000-00200, Nairobi

* Corresponding author: email address: podote@gmail.com; podote@kmfri.co.ke

Abstract

A sand base solar tunnel dryer was fabricated at Gazi, Kwale – Kenya and its effectiveness in drying mackerel (*Rastrelliger kanagurta*) was compared to that of an open air drying rack. The dryer consisted of a collector, drying cabinet and a photovoltaic system. The collector was covered with UV stabilized polyethylene while the drying cabinet's roof was made of glass. Direct Current fans, one for driving air in and another for extracting air were used. The drying rack measuring 10m by 1m made of mangrove poles with timber support for the nylon mesh on which the fish were laid.

The starting weights of the mackerel were 95.0 ± 18.02g and 96.7 ±5.77g in the solar dryer and drying rack respectively. The net drying time was 28 hours over a period three days. There was a significant difference ($p<0.05$) in the rate of the mackerel's weight loss in the solar tunnel dryer and on the drying rack. The moisture in the fresh fish reduced from 70.6%±0.9 (2.40kg/kg, db) to 14.5%±6.6 (0.17kg/kg, db) in the solar dryer and to 39.3%±3.4 (0.65kg/kg, db) on the rack. The drying rate constants for the solar- and rack-dried mackerel were 0.0772 h^{-1} and 0.0436 h^{-1} respectively. Drying was more uniform with the solar tunnel dryer compared to the rack dryer with drying coefficients (R^2) of 0.7544 and 0.4116 respectively. The mean temperature during the entire drying period was 57.6°C in the solar tunnel dryer and 35.6°C in the drying rack respectively. The mean humidity during the entire drying period was 46.4% in the solar tunnel dryer and 47.2% for the drying rack.

This study provides information for design engineers in the food industry in the design and operation of post-harvest fish drying facilities using low cost solar energy systems

Key Words: Solar tunnel dryer, Drying rack, Moisture content, Humidity, Temperature

Abbreviations: db = dry basis, DR = Drying Rack SD = Solar Tunnel, Dryer

INTRODUCTION

In the coastal region of Kenya, very little fish is landed by artisanal fishermen between the months of April to early September while October to March is characterized by glut and it is not possible to process the excess harvest which results in massive spoilage losses of fish by fishermen. The fishermen sell some of the fish cheaply to middlemen with the rest going to waste (Kimani *et al.*, 2018). Therefore, there is need to improve on the post harvest techniques to reduce losses by fishermen, and improve their earnings, in addition to contributing to food security.

Open sun drying is a common post harvest preservation method in the fish industry. The fish is laid on the ground or on rocks by the shores of the ocean (Kimani *et al.*, 2018). The drying process is slow and unhygienic, and is subject to dust contamination, insect infestation, and exposure to harmful human and animal handling and destruction by rodents among other pests. If drying is near homes, the fish has to be brought inside every time it rains and each evening to avoid dew and consequences such as moulds. The process results in very low quality fish with possible high moisture and limited demand in the market, high spoilage rates, higher labour in put and low income for the fishermen, in addition to loss of the fish as a source of proteins, community food security is also lost (Bala & Mondol, 2001; Sankat & Mujaffar, 2004; Mujaffar & Sankat, 2005; Sablani *et al.,* 2003). There is need to improve the quality of dried fish through technology advances in order to reduce post harvest losses and create a wider appeal for the cured fish market.

Drying racks, which are raised ventilated platforms, have been used widely in the drying of fish. The racks rely on air circulation around the product to evaporate the excess moisture, and their use reduces soiling of fish during drying. However, infestation by insects, rain and aerial contamination remain a problem during rack drying. Attempts to use improved solar drying technologies such as solar dryers in Kenya were carried out by Shitanda and Wanjala (2006) and Uluko *et al.,* (2004) but none addressed fish drying. The use of solar dryers provides an improved environment where temperatures are raised and fish is secured from most contaminating agents (Bala, 1997; Bala, 1998; Bala, 2009; Doe et al, 1977; Ahmed *et al.,* 1979; Rao *et al.,* 1987; Curan & Trim, 1982). One of the disadvantages of such dryers is the problem of internal air convection (Bala & Woods, 1994, 1995; Bala & Mondol, 2001). For effective drying, hot and dry moving air is employed. These factors are inter-related and it is important that each is correct. For instance, cold moving air or hot, wet moving air are each unsatisfactory. Attempts to utilize improved dryers with forced air convection have been made in the drying of various food products such as fruits, cereals grain legumes, oil seeds, and spices (Esper & Mühlbauer, 1993; Bala, 1997; Bala & Mondol, 2001; Bala *et al.,* 2005; Hossain *et al*, 2005, Reza *et al,* 2009). Most of these dryer designs expose the drying material to direct sun light.

A solar tunnel dryer has the capacity to improve on the quality of the dried fish as it has a partially dark drying chamber which secures material from exposure to direct sunlight in addition to elimination of most of the contaminants from accessing the drying fish. The objective of this study was to evaluate the performance of a sand base tunnel dryer against that of an open sun-drying rack in the drying of mackerel (Rastrelliger kanagurta).

METHODS

Solar tunnel Dryer construction

The, solar tunnel dryer (Fig. 1), was a modification of a solar tunnel dryer described by Bala and Mondol (2001). It was designed and fabricated at the Jomo Kenyatta University of Agriculture and Technology (JKUAT) in consultation with Kenya Marine and Fisheries Research Institute (KMFRI). The dryer consists of a solar collector chamber, a drying chamber and a photovoltaic system.

Fig. 1: Solar tunnel fish dryer

Solar Collector

The solar collector was a 7m long, 2m wide and 0.3m tunnel raised 0.4m above the ground. The maximum height at the center was 450mm above the collector base. The top outer cover was made from two layers of UV (Ultra Violet) treated polythene sheet of 500G (0.5mm). The base of the collector was made up of a 2mm thick metal plate painted black for heat absorption and encased in a sand layer for refractory and heat storage purposes. Below the sand layer was a 5mm thick wooden layer followed by a 20mm thick coconut fibre layer, both for insulation purposes. At the bottom were a 2.5mm wooden layer and a 0.5mm polythene layer for encasing the collector. The sides of the collector were made of a 2mm thick black painted metal for heat absorption, and lined by a 50mm thick coconut fibre layer for insulation. The outer surface of the collector wall was a 25mm thick black painted wooden layer for absorbing heat. To facilitate the forced air convection in the drying chamber, a 2m by 0.6m galvanized sheet plenum mounted with a 40W DC fan was fixed onto the collector.

Drying Chamber

The drying chamber was a cabinet measuring 2m wide, 2m long and 1.4m high and 0.5m above the ground surface. The maximum height of the dryer was 1.55m above the base of the cabinet. The sides of the dryer were made from 25mm thick plywood, which was lined with 0.05mm galvanized iron sheet for reflection and painted black on the outside for heat absorption. The base of the dryer cabinet was lined with 0.05mm aluminium sheet for heat reflection and ease of cleaning. A 5mm thick wooden layer, followed by a 50mm coconut fibre layer and finally a 2.5mm wooden layer for insulation encased the aluminium sheet. The roof of the drying cabinet was made from 4mm thick glass to allow for solar radiation into the cabinet and ease of inspection during the drying process. The chamber had three shelf layers for holding twelve wire mesh trays measuring 1m by 1m, and spaced 200mm apart with a maximum capacity of 200kg of fish. These were accessed from the side of the dryer cabinet via hinged doors, which could be opened wide to allow for sliding the trays into and out of the drying cabinet during loading or offloading of fish. At the outlet of the dryer cabinet an exit plenum 2m wide by 1.4m wide and fitted with a chimney 30mm in diameter and encased with a 40W DC fan was fitted to facilitate the removal of moist air from the drying chamber. The power supply system for the solar dryer was a photovoltaic system consisting of a 100W solar panel and a 100Ah deep cycle battery. This power system was used to power two axial 40W DC axial fans with a capacity of 0.46 m^3/h.

The drying rack

The traditional drying rack (Fig. 2) consisted of mangrove support frames. The rack was 10m long, 1m wide and 1m high. The top was covered by nylon mesh to avoid rust and therefore ideal for use by the sea.

Fig. 2: Raised rack fish drying

Site selection

The site selection was purposive. Gazi area was selected due to the presence of an organized community-based group (*Mpaaji ni Mungu*) who showed interest in running the project. Gazi is located in Kwale District in the south coast of Kenya. It is set on a mangrove filled bay just off the road towards the south and about 50km from Mombasa. The village lies 4°25'S, 39°30'E, and has its major landing seasons as October and March.

Drying of Mackerel

A total of 240 fresh mackerel were purchased from the local fishermen in Gazi a day before solar drying in late November 2012. The selection of the fish samples was such that only sound, wholesome fish, free from adulteration and organoleptically detectable spoilage, and of relatively the same size were subjected to further processing. After selection, the fish were de-scaled, de-gilled, split open and eviscerated. They were washed thoroughly and salted at a ratio of 1:10 salt to fish in a wooden trough for a period of 16 hours, from early evening to the following day before drying. The fish were layered alternately with salt first at the bottom of the trough followed by fish. Salt and fish layers alternated with the salt layer finally at the top. The fish were washed to remove excess salt, and placed in trays, under a shade where they were held at an angle for 1 hour to drain excess water.

After the preparation, half of the fish were distributed randomly and laid in single layers on the drying trays in the drying chamber of the solar tunnel dryer. The other half were also distributed randomly on the drying rack lying next to the solar tunnel dryer and with the drying rack kept the same height as the drying trays of the solar tunnel dryer. Three (3) representative samples of fish were taken at random from the solar tunnel dryer and traditional rack and weighed using a digital field balance (SALTPETERSK 2000-BLACK & DECKER, USA), to give the average starting weight of the fish before drying started. Every 2 hours during the period of drying, fish weight, moisture content, drying air temperature and humidity for the drying inside the drying cabinet and on the drying rack. On day-one, measurements were taken at 2 hours interval from 09.30am to 05.30; that is, at 0, 2, 4, 6, 8 hours. On day-two measurements continued from 08.15am to 06.15pm at two hour intervals i.e. (23, 25, 27, 29, 31, 33 hours from day-one). On day-three measurements continued from 8.15am to 2.15pm at two hour intervals i.e. (47, 49, 51, 53 hours from day-one). Temperature and humidity during drying was measured every 2 hours using a DICKSON TH300 (USA). Fish weight was determined by randomly weighing three (3) representative pieces of fish from the solar tunnel dryer and dryer rack every two hours and returning the fish in the dryer. Three randomly selected fish were also sampled for moisture content determination every two hours during the drying period. They were removed and wrapped in aluminium foil, and put in seal lock bags, before being labeled and placed on ice in ice boxes, after which they were taken to the laboratory in KMFRI and stored at -18°C till analysis.

Moisture content was determined according to Helrich, (1990), while moisture loss as weight loss during drying after every 2 hours was evaluated by getting the difference between starting and subsequent weight. The moisture ratio was evaluated using the equation 1 (Henderson, 1976; Kituu *et al,* 2008; Uluko *et al*., 2006).

$$MR = \frac{M}{M_0} = \exp(-kt) \quad (1)$$

RESULTS

Weight loss

The weight loss for mackerel in the solar tunnel dryer was from 95.0 ± 18.0g mean initial weight to 20.0±13.2g (Fig. 3) in day-one, which was equivalent to 78.9% loss, while in the drying rack the weight loss was from 96.7 ± 5.8 to 26.7 ± 2.9, equivalent to 64.4%. In day-two, the weight loss in the solar tunnel dryer and drying rack were from 23.3 ± 17.6g to 13.3 ± 7.6g, from 28.3 ± 5.7g to 16.7 ± 2.9g, equivalent 42.9%, and 40.9% loss, respectively. In day-three the weight loss was 13.3±7.6g to 8.3±2.9g or 37.6%, and 16.7±2.9g to 10.0±0g or 40.1% respectively for the solar tunnel dryer and the drying rack. There was no significant weight loss in day-three; therefore, the experiment was stopped after 53 hours from day-one. The relationship between weight loss and drying time for the rack drying and tunnel dryer is presented in Fig. 3.

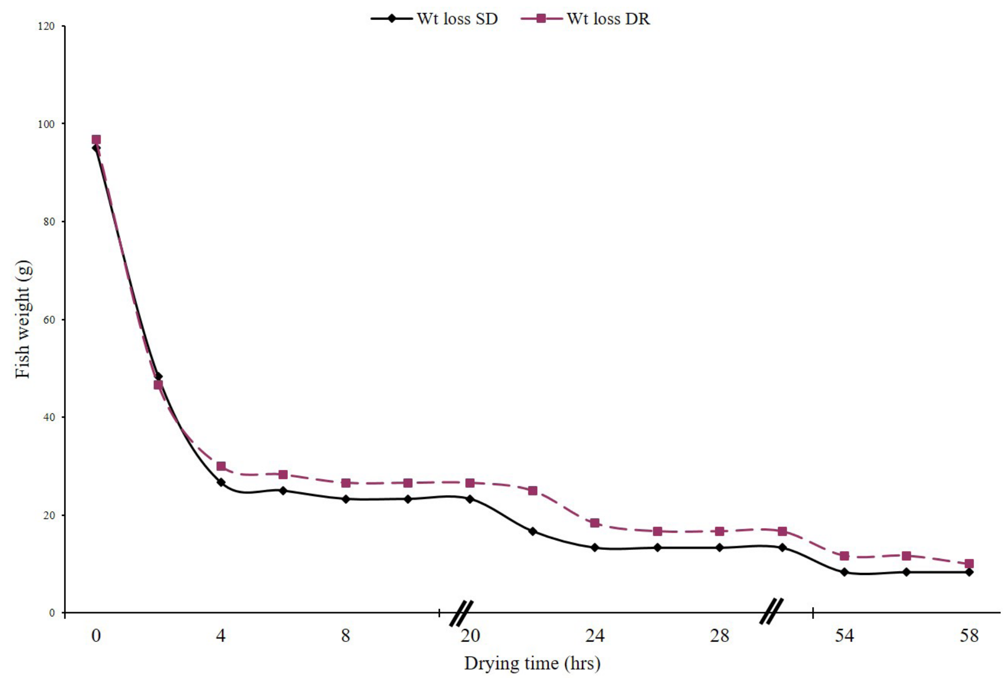

Fig. 3. Weight loss of mackerel each day in SD and DR

The overall moisture loss was 91.2% for the fish dried in the solar tunnel dryer and 89.6% for the fish dried in the drying rack at the end of the drying period. There was a statistically significant difference in weight loss ($p < 0.05$) between the solar tunnel dryer and the drying rack.

The variation in moisture content with time during drying of mackerel in the solar tunnel dryer and rack dryer is shown in Fig. 4. The initial moisture content of fresh mackerel was 2.40 kg/kg (db), or 70.6% ± 0.9 which decreased to 0.17 kg/kg (db) or 14.5% ± 6.6 and 0.65kg/kg (db) or 39.4% ± 3.4 respectively in the solar tunnel dryer and the drying rack at the end of drying.

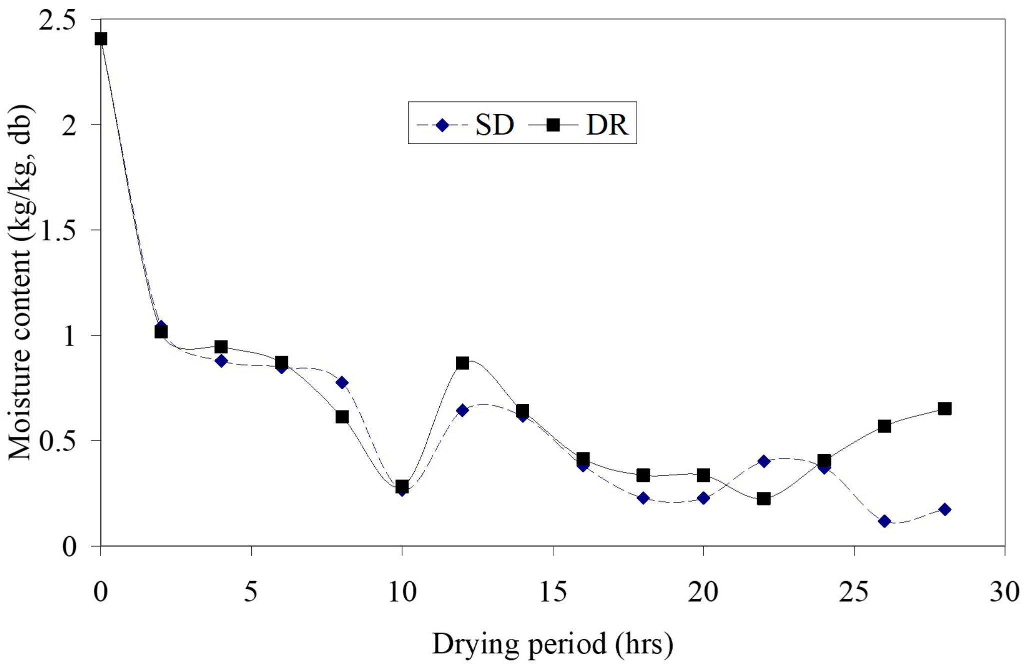

Fig. 4. Variation of moisture content against time for mackerel dried SD and DR

The moisture ratio for mackerel dried in the solar tunnel dryer and drying rack was presented as a reduction in moisture ratio with time for both types of drying environment (Fig. 5).

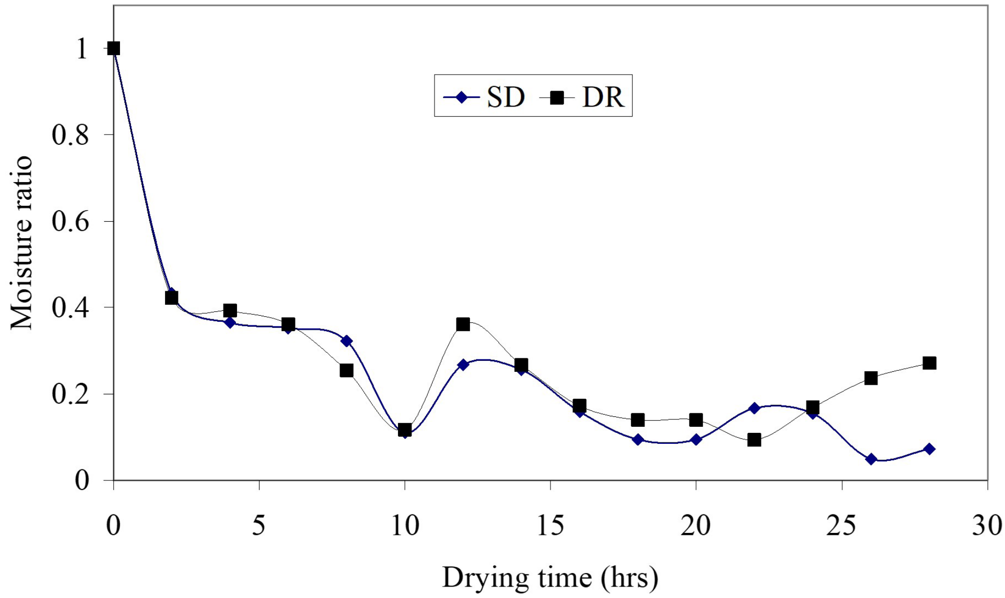

Fig. 5. Change in moisture ratio with time for drying mackerel in a SD and a DR

The change in the natural log of moisture ratio (MR) versus time for the mackerel dried in the solar tunnel dryer and drying rack is as presented in Fig. 6. The figure also presents the best curves of fit for the relationship, the equation describing the best curves of fit and the corresponding coefficients of determination (R^2).

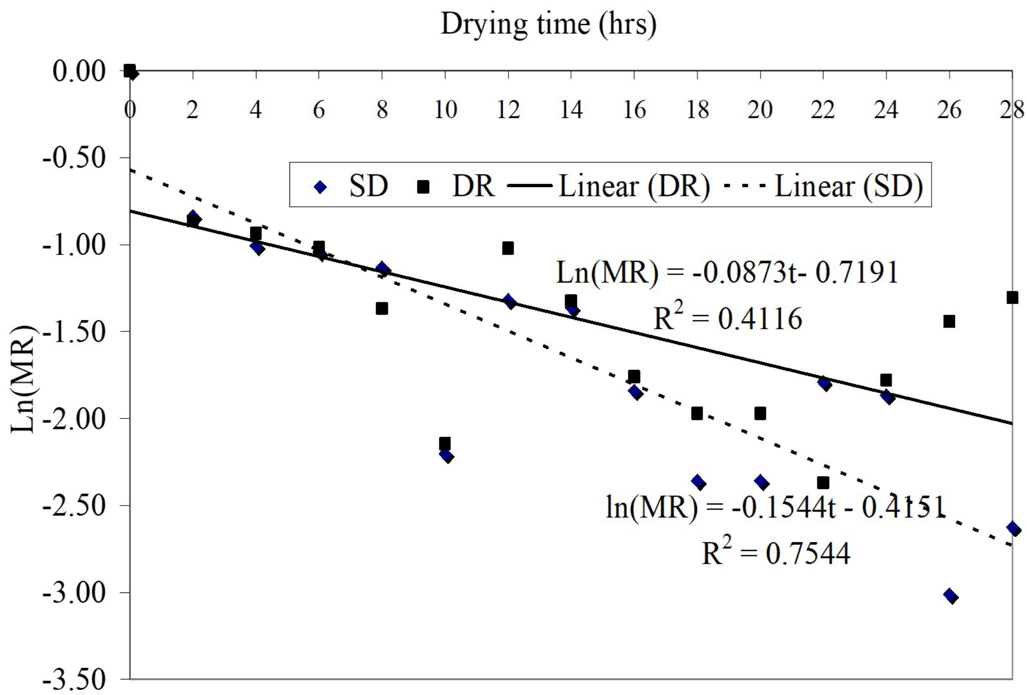

Fig. 6. Relationship between natural log of MR and time for mackerel dried in SD and DR.

The drying rate in the solar tunnel dryer and drying rack are shown in Fig. 7. More variations in drying patterns were observed in the drying rack than in the solar tunnel dryer.

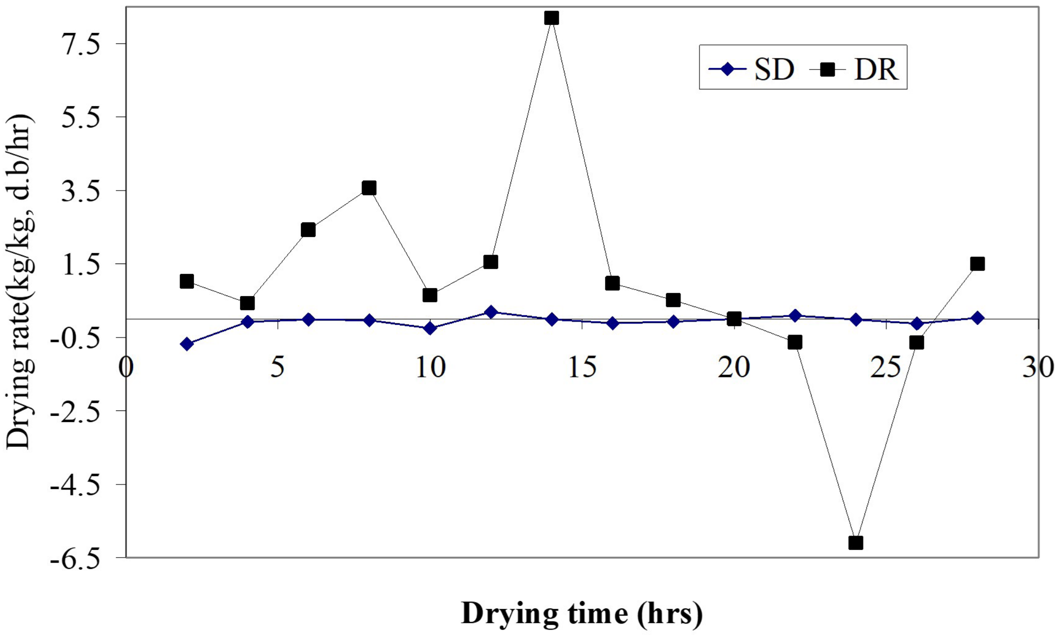

Fig. 7. Drying rate of mackerel in SD and DR

The drying rate constants for the drying of fish in the solar tunnel dryer and rack dryer are presented in Table 1. The drying rate constant for the solar dried mackerel was 0.0772 h^{-1} and for the rack dried 0.0436 h^{-1}.

Table 1: Drying equation parameters for mackerel drying in both SD and DR

	k (hr^{-1})	Coefficient of determination (R^2)
Solar Dryer	0.0772	0.7544
Drying Rack	0.0436	0.4116

Changes in temperature and humidity during the drying period are shown in Fig. 7. The mean daily and overall mean values for temperature and humidity during the drying period are presented on Table 2. Temperature increased in both the dryer and rack as the day progressed peaking between 10.00 hours and 14.00 hours. The mean temperatures in the solar tunnel dryer in da-one, day-two and day-three were 56.2°C and 56.3°C and 60.3°C respectively, while in the drying rack they were 35.3°C, 33.8°C and 37.5°C respectively for day-one, day-two and day-three. The mean temperature during the entire drying period was 57.6°C in the solar tunnel dryer and 35.6°C in the drying rack. Humidity decreased more in the solar tunnel dryer as drying progressed and was lowest in the solar tunnel dryer between 10.00 hours and 14.00 hours. The mean humidity in the solar tunnel dryer in day-one, day-two and day-three was 48.4%, 44.7% and 46%. In the drying rack it was 47.9%, 47.0% and 46.8% in day-one, day-two and day-three. The mean humidity during the entire drying period was 46.4% in the solar tunnel dryer and 47.2% in the drying rack.

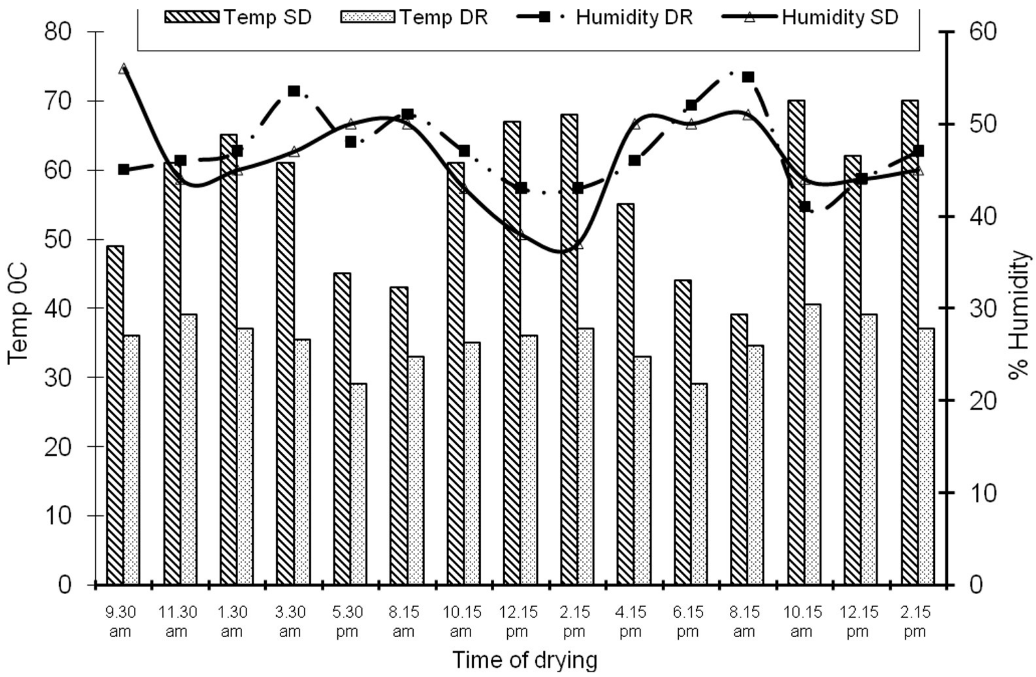

Fig. 7: **Humidity and temperature in SD and DR**

Table 2: Mean daily Temperature and % Humidity in solar tunnel dryer and drying rack

	Solar tunnel dryer		Drying rack	
	%Humidity	Temperature°C	%Humidity	Temperature°C
Day 1	48.4±4.8	56.2±8.6	47.9±3.3	35.3±3.8
Day 2	44.7±6.2	56.3±10.1	47.0±3.8	33.8±2.9
Day 3	46.0±3.4	60.3±14.7	46.8±6.0	37.8±2.6
Mean	46.4±1.9	57.6±2.3	47.2±0.6	35.6±2.0

DISCUSSION

Drying of fish in both the solar tunnel dryer and rack dryer was identified to be within the falling rate period, during which, the surface of the substance is still fairly dry, with drying resulting from moisture migration from the fish flesh to the surface and subsequent evaporation. The predominant factor that contributes to drying is heat, which causes evaporation of water from the fish, while the contribution of air in drying is effective when the moisture is at the surface. The fish in the solar tunnel dryer was at higher temperatures. This allowed the drying process to continue as any resistance against the water vapour flow to the surface was reduced by the effect of higher temperatures compared to the drying rack (Sankat & Mujaffar, 2004). The lower the humidity and the higher the temperature, the faster is the rate of drying (Mujaffar & Sankat, 2005).

Dryers that give better drying rates have lower humidity and higher temperatures inside the drying units (Sablani *et al.* 2003). Drying temperatures of 50°C and humidity of up to 50% have been considered ideal in the drying of fish (Bala & Mondol, 2001; Sablani *et al.,* 2003). In this study, the mean temperature in the solar tunnel dryer was 57°C and in the drying rack 35°C. The mean humidity was 46.4% in the solar tunnel dryer and 47.2% in the drying rack. During peak heat periods in this study between 10.00 hours and 14.30 hours, humidity varied inversely to temperature during drying. It can be postulated that higher temperatures maintained inside the solar tunnel dryer as a result of solar insulation on the collector, followed by subsequent transfer of the heated air by forced convection over the fish, coupled with direct radiation into the cabinet dryer and lower humidity were responsible for the faster drying rate of the fish.

During the drying period on the drying rack, ambient temperatures ranged from 33°C to 37°C, and were not as high as those developed inside the tunnel dryer. Such temperatures are however not ideal for drying of fish unless aided by another factor. Mujaffar and Sankat, (2005) describe such an occurrence where Shark fillets dried at 30°C in an oven without air movement were discarded after 16 hours due to spoilage. The rack was located by the sea side where wind is quite strong. The seaside wind increased the drying rate by removing more surface moisture and creating room for more moisture migration to the surface. However, the drying potential still needed to be increased by heat, which was lower in the drying rack and hence the low drying in the rack. Although wind alone can cause surface drying and might not influence the internal water content of the fish significantly, the rapid drying rate was occasioned by strong air currents at the height of the raised rack that passed freely over and below the fish, picking up moisture and thereby increasing moisture migration from the surface of the fish (Chamberlin & Titili, 2001).

The initial moisture content in fresh mackerel on dry basis was 2.40kg/kg. This decreased to 0.17kg/kg (db) in the solar tunnel dryer and to 0.65kg/kg (db) at the end of drying in the drying rack. There was a greater decline in moisture content in mackerel dried in the solar tunnel drier than on the drying rack. The moisture content declined rapidly with time from the initial values of 2.40 kg/kg (db) to 0.776 kg/kg (db) on day-one for the fish dried in the solar tunnel dryer and to 0.61 kg/kg (db) for fish dried in the drying rack. During this time, there was no distinct difference in decline in moisture content between the fish in the solar tunnel dryer and the drying rack.

After this rapid initial change in moisture content, the reduction in moisture content became gradual to a final moisture of 0.17 kg/kg (db) and 0.65 kg/kg (db) in the solar dryer and drying rack respectively Such observations were also made by Bala and Islam, (2001), Sablani *et al.,* (2003), Sankat and Mujaffar, (2004), Mujaffar and Sankat, (2005), Sereno *et al,* (2001), Mujaffar and Sankat, (2006).The drying rate constant (k) for the drying period was 0.0772 $h^{-1}$for the fish dried in the solar tunnel dryer and 0.0436 h^{-1} for the fish dried in the drying rack. These constants were higher in the solar dried fish than for the fish dried on the rack, implying superior performance of the solar tunnel dryer compared to the drying rack when used to dry mackerel.

Moisture content is affected by drying time according to Sablani *et al.,* (2003). The decline in moisture content (db kg/kg) in the solar tunnel dryer was more uniform and regular than in the drying rack. This is seen in the best line of fit relating moisture content and moisture ratio with time (Fig. 6). The coefficient of determination (R^2) was 0.7544 for solar tunnel dried fish and 0.4116 for fish dried on the drying rack. This observation implies that a strong relationship exists between moisture ratio and time for fish dried in a solar tunnel dryer than in a rack dryer. This then translated to better uniformity in the drying process for fish dried in a solar tunnel dryer (Fig. 7).

The non uniform moisture decline in the drying rack was due to the absence of control in the drying parameters including wind, temperature variations and humidity (Mujaffar and Sankat, 2005). Any changes in humidity in the atmosphere may lead to reabsorption of moisture since dry fish muscle is quite hygroscopic (Daramola *et al.,* 2007; Wood, 1981) and fish shape is heterogenous. The fish contained up to 2.4 kg/kg (db) moisture content. When moisture content is reduced to 0.33kg/kg (db) contaminating agents cannot survive, and autolytic activity is greatly reduced (Bala & Mondol, 2001). However, to prevent mould growth during storage moisture must be reduced to 0.18 kg/kg, (db) (Bala & Mondol, 2001). In this study the final moisture content of the mackerel was 0.17kg/kg, (db) for fish dried in the solar tunnel dryer and 0.65 kg/kg (db) for those dried in the drying rack. The fish dried in the solar tunnel dryer therefore contained the desirable moisture content for storage that would prevent mould growth.

CONCLUSIONS

The initial moisture content of the mackerel (2.4 kg/kg, db) was reduced to 0.17kg/kg (db) and 0.65 kg/kg (db) in the solar tunnel dryer and the rack dryer respectively in three drying days. The drying rates for the fish drying in the tunnel dryer and rack dryer respectively were 0.0772 and 0.0436 per hr. The relationship between moisture content and drying time for both tunnel drying and rack drying was exponential. A strong relationship exists between moisture content and drying time for solar tunnel dried mackerel since the coefficient of determination was high (R^2=0.7544), in comparison, the rack dried fish demonstrated a weak correlation with a low coefficient of determination (R^2=0.4116). The final moisture content for solar-tunnel and rack dried mackerel respectively were 0.17 kg/kg (db) and 0.65kg/kg, (db). The final moisture content for solar tunnel dried fish was within the acceptable rage for stored dried fish. Rack dried mackerel did not meet the threshold. Drying was more uniform and the fish dried to a lower moisture content (14.5%) ideal for longer shelf life for fish dried in the tunnel dryer. The higher drying rate constants confirmed superiority of the solar tunnel dryer over the drying racks. Humidity did not very much in both the tunnel dryer and rack and may not have been crucial in drying differences. Temperature range between the dryer and the rack was wide and could have contributed more to the drying process. This study concludes that the sand base solar tunnel dryer provides a good alternative for drying mackerel fish earmarked for storage especially during seasons of fish glut along the coastal region.

ACKNOWLEDGEMENTS:

The authors would like to thank the Lighthouse Foundation of Germany for funding this research. The leadership and staff of KMFRI and JKUAT are acknowledged especially Mr. S. Tunje, Mr I. Mukolwe, Mr. C. Odoli and Mr. B. Ohowa. We are also grateful to the Mpaaji ni Mungu Women Group for their participation.

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Kenya Aquatica Journal. Vol. 6, No. 1, pp.52-58 , 2021

Ocean Climate Solutions: Blue carbon Now Incorporated in the Updated Kenya's Nationally Determined Contributions to Paris Agreement

James Kairo* and Joseph Langat

Blue Carbon Unit, Kenya Marine and Fisheries Research Institute

P.O. Box 81651, Mombasa

Corresponding author's email; jkairo@kmfri.co.ke; gkairo@yahoo.com

Introduction

Climate debate has seen enhanced interests in ocean-based climate solutions, with a lot of focus being laid on blue carbon ecosystems. Blue carbon (BC) describes the carbon storage potential of vegetated coastal ecosystems, including tidal marshes, mangrove forests, and seagrass meadows (Donato, *et al.,* 2011,) Although they occupy less than 0.05% of the sea bed, BC account for 50-71% of the entire C stored in the ocean sediments and are ranked as the most intense C sink on earth (Nelleman & Corcoran 2009; Donato *et al*., 2011). Unfortunately, BC are being degraded globally at an alarming rate of 1-7% per year, which is significantly higher than the global loss of tropical forests, estimated at 0.5% per year (ref.). When these BC are degraded, they not only halt to take up more carbon, but most important they release the already stored carbon back to the atmosphere leading to global warming (Pendleton *et al*., 2012). Restoration and protection of BC is, therefore, recognized as a priority for both climate change mitigation and adaptation; and several countries have identified measures that harness these benefits in their National Determined Contribution (NDCs) to Paris Agreement (McLeod *et al.,* 2011).

Blue carbon in Kenya is mainly represented by mangroves and seagrass beds (Fig 1). There are 60,323ha of mangroves in Kenya, representing only 1% of country's area (GoK, 2017). These forests play an important role in the nationals and regional economies including provisions of wood and non-wood products to the people, supporting fisheries, coastal protection and stability as well as contributing to biodiversity conservation (Bosire *et al*., 2016; Hamza *et al*., 2020). Total carbon stocks of mangroves in Kenya have been estimated at 560MgC/ha. Within the last four decades, some 40% of mangroves have been lost emitting 12Mt-CO_2-eq. The loss has mostly been associated with over-harvesting of wood products, habitat conversion, pollution, and climate change **(**Kirui *et al*., 2012, Bosire *et al.,* 2014, GoK, 2017). Total area of seagrass in Kenya ranges from 30,800 to 31,700 ha, with a an estimated total ecosystem carbon stocks of 8 MtC and a carbon sequestration rate of 0.026 MtC yr^{-1} (Githaiga *et al.,* 2017; Harcourt *et al.,* 2017). Seagrass cover change analysis has revealed a decline in coverage at a rate of 0.85% yr^{-1} since 1986, which has resulted in a release of upto 2.7 MtC (Harcourt *et al.,* 2017). This loss has been attributed majorly poor fishing activities.

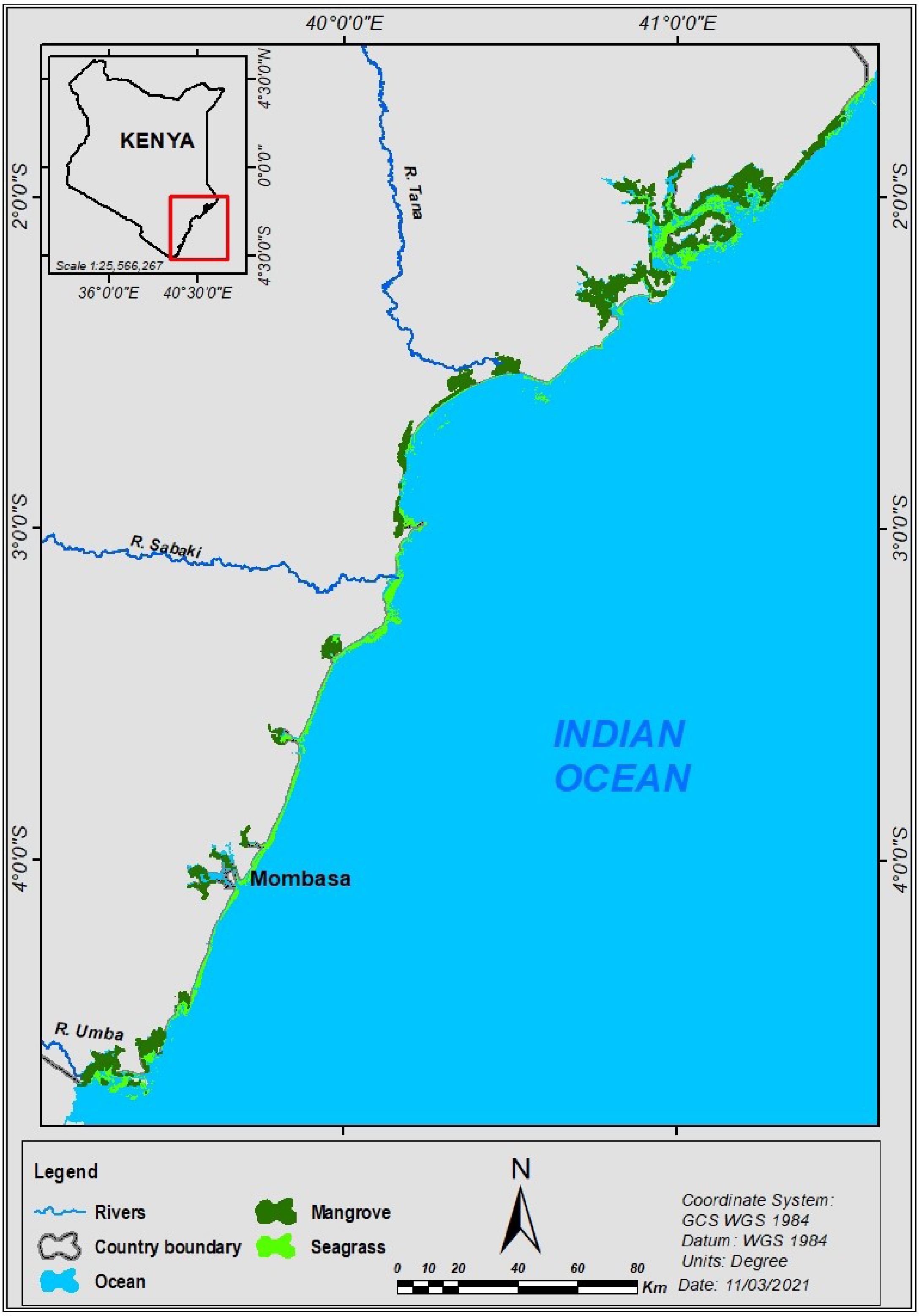

Fig. 1. Mangrove forests along the Kenya coast (to be updated)

Kenya's NDCs

Kenya is very vulnerable to climate change effects; with current projections suggesting that its temperature will rise by up to 2.5°C between 2000 and 2050, while rainfall will become more intense and less predictable (ref). Food security, rural livelihoods, human health, physical infrastructure and water resources rank high among climate change vulnerability concerns along the coast and the country in general (NCCAP, 2018).

Addressing climate change requires that we transform our economy by integrating climate change into national and county development plans. This will lower greenhouse gas emissions, reduce our vulnerability to climate impacts and deliver poverty reduction gains because taking action to adapt to and mitigate climate change is in our national interest.

Kenya submitted her first NDC on 28th December 2016 to the United Nations Framework Convention on Climate Change (UNFCCC). This NDC committed a 30% reduction in greenhouse gas (GHG) emissions by 2030, relative to a business-as-usual (BAU) scenario of emitting 143 $MtCO_2e$ annually (GoK, 2015).

Achievements of the NDC commitments were subject to international support in the form of finance, investment, technology development and transfer, and capacity building. The NDC identified mitigation options as well as key sector vulnerability and adaptation issues for agriculture, water, aquatic and marine resources, energy, health, and the social economic context in general. Under the forestry sector, establishment of forest cover of at least 10% was identified as climate change mitigation measure (GoK, 2015). Despite their high carbon sequestration rates (Gress, *et al.*, 2016) and the multiple ecosystem services they provide (Huxham et al., 2015) mangrove forests were not integrated in the initial NDCs. This gap presented an opportunity to enhance ambition in the country's updated NDCs.

Kenya Marine and Fisheries Research Institute (KMFRI) with support from Pew Charitable Trust, The Nature Conservancy (TNC), UN Blue Forest Project, Wetlands International, Conservation International, WWF, IUCN, and Napier Edinburgh University (UK) supported the country's ambition to incorporate blue carbon ecosystems into the Updated NDC. A National workshop on mangroves and NDCs was held on 28th – 31st October 2019. Over 116 participants from National and County Governments, non-governmental organizations, private sector, academia and community- based organizations attended the workshop (ref).

NDC review process

On 28th December 2020, Kenya's Updated Nationally Determined Contribution (Updated NDC) was submitted to UNFCCC. In the Updated NDC, Kenya sets to abate her GHG emission by 32% by 2030 relative to the BAU scenario of 143 $MtCO_2$ eq, and in line with national development agenda. Contributions described in the updated submission built upon Kenya's initial NDC, National Climate Change Action Plan (NCCAP) 2018-2022, National Adaptation Plan (NAP) 2015-2030, and new sectoral and national plans. The sector-wide consultative framework provided an opportunity to re-look at the NDC revision process and ensure that ocean climate actions were incorporated.

Ocean climate actions

Our increased understanding of the ocean and its potential role in climate change mitigation and adaptations compels us to include ocean-based climate actions in the revision of NDCs. Oceans cover 70 percent of the earth's surface, produces more than 50 percent of the oxygen we breath and absorb more than 90% of the heat trapped in the atmosphere (IPCC, 2019). A healthy ocean is critical for achieving global development goals and climate change targets.

The Intergovernmental Panel on Climate Change (IPCC's) Special Report on Oceans and Cryosphere (SROCC) alerts the world over the expected risks of climate change if greenhouse gas is unabated (IPCC, 2019). In Kenya, effects of climate change are already witnessed in the bleaching events and death of coral reefs, loss of mangroves, and reduction in major fisheries (Kairo & Bosire, 2016; Gudka *et al.*, 2018). A sustainable ocean-based economy can play an essential role in this much needed emissions reduction, while providing jobs, supporting food security, sustaining biological diversity and enhancing resilience (Obura, 2017; Stuchtey *et al*., 2020). Ocean based climate action could protect coasts against climate change effects (such as sea level rise and erosion), restore coastal and marine ecosystems, and help to mitigate climate change by sequestering carbon.

Kenya aims to achieve her Vision 2030 through low carbon climate resilient development pathway. Harnessing the mitigation benefits of sustainable blue economy, including blue carbon payments for ecosystem services (PES) are among ambitious ocean-based climate mitigation actions in the Updated NDCs. Adaptation, however, is the highest priority for Kenya, not only through preventing further losses and damage but also mainstreaming climate change adaptation into the Medium-Term Plans (MTPs) and County Integrated Development Plans (CIDs). Blue carbon ecosystems have been included in the priority ocean-based adaptation actions in the Updated NDC (Table 1).

Table 1: Ocean based adaptation actions identified in Kenya's updated NDC (2020)

Sector	Priority Action
Disaster risk reduction	Flood risk management incorporating nature-based solutions, including; mangrove reforestation.
Environment	Rehabilitation and conservation of degraded forests, that include mangroves.
	Enhance governance structures in participatory resource management in coastal ecosystems.
	Conduct blue carbon readiness assessment for full integration of **blue carbon/** ocean climate actions into NDCs.
	Develop marine spatial planning and outline sustainable management approaches
	Promote and expand opportunities for nature-based enterprises including seaweed farming and mangrove ecotourism.
	Integrate the use of nature-based solutions, including the implementation of national mangrove management plan into national and county development plans.

The total cost of implementing mitigation and adaptation actions of the Updated NDC is estimated at USD62 billions over the next 10 years; with a stock taking expected in 2025. Compared to the first submission that was fully conditional to support, in the revised NDC, Kenya intends to bear 13% of the implementation cost from domestic budget with the balance coming from the international support in form of finance, technology development and transfer, and capacity building (GoK, 2020).

Enablers of ocean climate solutions inclusions in the updated Kenya's NDC

We reviewed a total of 14 policy documents, legislations and sectoral plans in order to identify opportunities and gaps for inclusion of climate ocean solutions in the Updated NDCs (Table 2). All the reviews documents provide enabling frameworks and opportunities within which ocean climate actions could be mainstreamed into Kenya's development and climate agenda at both national and county levels. However, fundamental gaps regarding ocean climate actions were identified, mainly due to paucity of data and information on the sector. Building on these enabling frameworks and addressing the gaps highlighted provide great opportunity for fully integration of ocean climate solutions into future NDCs.

Table 2: Reviewed policy, legislations, and sectoral plans documents

Policy and Legislations	Gaps	Opportunities
i) Constitution of Kenya, 2010 ii) National Climate Change Framework Policy iii) Climate Finance Policy iv) Integrated Coastal Zone Management Policy, 2013 v) Climate Change Act 2016 vi) Forest Conservation and Management Act 2016 vii) Wildlife Conservation and Management Act 2013 viii) Fisheries Management and Development Act **National and Sectoral Plans** i) National Climate Change Action Plan, 2018-2022 ii) National Adaptation Plan, 2015-2030 iii) National Climate Change Response Strategy, 2010 iv) National Strategy for Achieving and Maintaining Over 10% tree Cover By 2022 xiii) Taskforce Report on Forest Resources Management and Logging Activities in Kenya, 2018) xiv) National mangrove management plan, 2017 – 2027.	i) The role of the ocean sector in climate change interventions is not adequately highlighted. ii) Risks and vulnerability of climate change on coastal and marine sector not well captured iii) Benefits of blue carbon ecosystems to climate, livelihood support, and biodiversity conservation not adequately highlighted, iv) Contributions of coastal wetlands have not been captured in the GHG inventory reporting and thus subsequently not included in the emissions projections. v) More emphasis is laid on the sectors in terrestrial settings and hence strategies and plans developed give more attention to priority actions in these sectors, e.g. Kenya Climate Smart Agriculture (CSA) and the System for Land-based Emission Estimation (SLEEK). But Policy issues and strategies specific to coastal and marine systems have not been adequately captured.	i) Review and provide updates on the status and conditions of blue carbon ecosystems; particularly, valuation of their ecosystems services to enable their integration to policy framework and national and county level development plans ii) Conduct vulnerability assessment of climate change of blue carbon ecosystems and develop their mitigation actions iii) Quantify the contribution of BC to emission reduction in order to include them in national GHG inventory reporting. iv) Develop strategies for designing and tracking programs for ocean climate actions and integrating them into MRV (measurement, reporting, and verification) framework v) Identify and develop ocean nature-based climate solutions to leverage on the established enabling aspects of climate finance mechanisms. vi) Develop strategies for the implementation of the National Mangrove Ecosystem Management Plan

Conclusion

The ocean sector has immense potential of contributing to solutions to climate change challenges. The incorporation of the ocean climate solutions, (in particular blue carbon) in the Updated Kenya's NDCs provide ambitious actions in line with. This is a substantial milestone for Kenya in its role of championing sustainable blue economy. Consequently, this calls for concerted efforts by actors in the ocean sector to utilize this opportunity to upscale the development of strategies for influencing ocean climate policy framework at county and national levels. Of particular importance is utilizing ocean climate solutions in harnessing benefits of associated with sustainable blue economy.

Acknowledgement

This study was funded by WWF-Germany and WWF-US, contract number BMZ 68776 granted to KMFRI by WWF-Kenya. Additional financial support was received from Pew Charitable Trust's Contract: 00032875 and The Nature Conservancy's Contract No. F104765 -KMFRIMANGROVE-09122019

both awarded to Dr. James Kairo.

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Kenya Aquatica Journal. Vol. 6, No. 1, pp.59-64 , 2021

Short Note

Blue Economy: Potential Use of Multibeam Echo-Sounders in Seafloor Mapping

Amon Kimeli* and Melckzedeck K. Osore

Kenya Marine and Fisheries Research Institute, P. O. Box 81651, Mombasa, Kenya.

*Corresponding E-mail: kimeli.k.amon@gmail.com

Introduction

To the ordinary Kenyan, the country covers an area of just over 580,000 km^2 comprising of the terrestrial landmass. However, Kenya also boasts of 9,700 km^2 of territorial sea and an extra 142,000 km^2 square kilometers of the Exclusive Economic Zone (EEZ) in the Indian Ocean. The more than 150,000 km^2 extra excluding the inland water bodies constitute the platform upon which Kenya can explore, develop, exploit and sustainably manage its Blue Economy. Figure 1 shows the map of the Kenya coast with track line of the hydro-acoustics surveys conducted by Kenya's RV Mtafiti from south to north including the EEZ. According to the United Nations Convention on the Law of the Sea (UNCLOS), every maritime state boasts of inherent sovereign rights on the territorial sea (up to 12 nautical miles equivalent to 22 km) and the EEZ extending to 200 nm (370 km). These sovereign rights include the exploration and exploitation of both living and non-living resources in the water column, the seafloor and beneath.

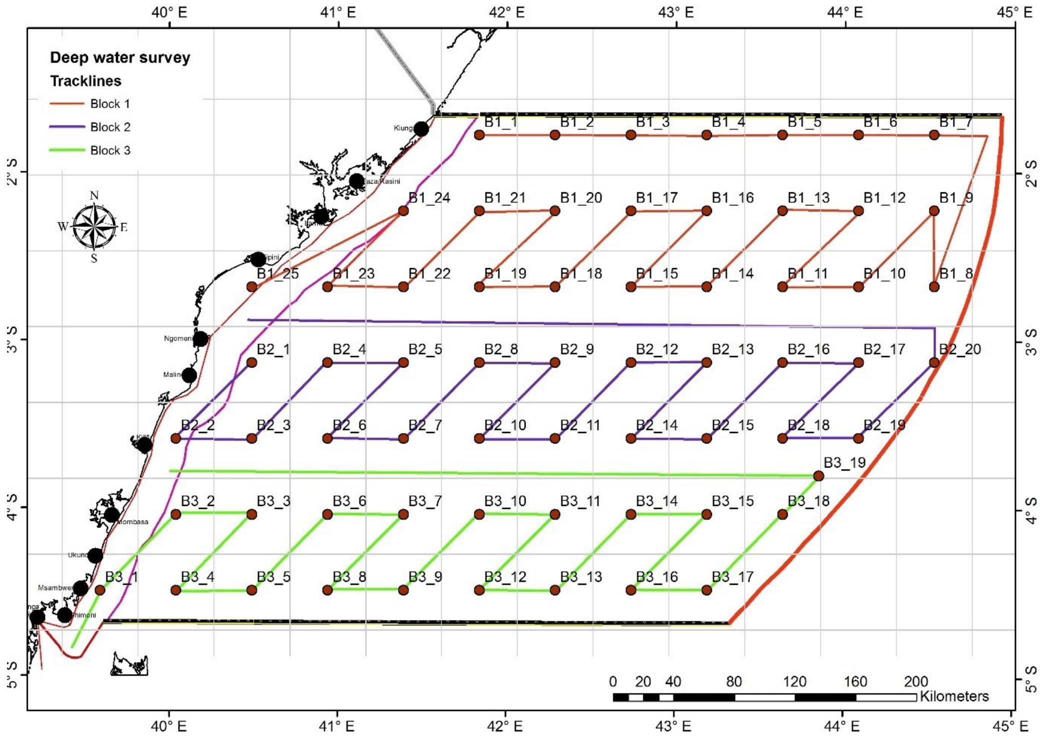

Fig.1: Map of the Kenya coast showing the track line of the hydro-acoustic survey conducted by RV Mtafiti between 2014 and 2020 from south to north including the EEZ

The ocean provides numerous economic, environmental and ecological values to mankind. These values include the air we breathe, food, transportation, climate regulation and mitigation, recreation and revenues through ocean-based economy. Increased knowledge of our oceans expands our understanding of our marine ecosystems and life that would hitherto unlock a huge potential and new opportunities. Among other key ocean management domains that would benefit from our enhanced knowledge on the ocean include integrated coastal zone management, maritime transport, marine spatial planning, ocean climate solutions, and ocean governance.

It would, therefore, be fair to ask about ocean economy and how much of the global seafloor we currently know.

According to a 2017 report by the World Wildlife Fund for Nature (WWF), if we were to consider the global ocean as a country, it would be the world's 7th largest economy with its Gross Marine Product (GMP) estimated at US$ 2.5 trillion. Closer home, the estimated Western Indian Ocean (WIO) region – comprising of African nations bordering the Indian Ocean along the East Africa coast - Gross Marine Product (GMP) was ranked the 4th largest at US$ 20.8 billion compared to Gross Domestic Product (GDP) of individual countries behind only South Africa (US$ 349.89), Kenya (US$ 60.9) and Tanzania (US$ 49.2). This is despite 85% of the global ocean seafloor remaining unmapped.

On the basis of these facts, it is inevitable and of high priority for the world and individual maritime states to see to it that the ocean seafloor is fully mapped. Bathymetry - the measurement of water depths relative to the sea level - started as early as 2000 BC and appeared for the first time in the 16th Century in European navigational charts as depth soundings and contours (OECD, 2016; 2019). Several bathymetric measurements are used to visualize the topography and relief of the seafloor. Bathymetry allows for the exploration of both living and non-living resources and understanding of the critical ocean and seafloor processes. Bathymetry mapping as we know it today started in 1807 when the then President Thomas Jefferson of the United States of America (USA) signed the Act named "Survey of the Coast" to provide for surveying and production of complete and accurate charts of the entire coast of the USA purposely to improve the safety of navigation and promote transatlantic maritime trade. Notably, a major sea-floor mapping was done between 1873 and 1876 aboard the research vessel the HMS Challenger during the famous grand world tour christened the "Challenger Expedition" covering a total of 128,000 km and organized by the Royal Society in collaboration with the University of Edinburgh. During the Challenger Expedition, a total of 492 bathymetric soundings were obtained and the first recording of the deepest part of the ocean at 10,920 m and subsequently named the Challenger Deep within the Mariana Trench in the Western Pacific Ocean was made. To give a real and relatable reference, the highest point on land is Mount Everest at 8,848m above sea level located at the Nepal-China border. With a heightened collection of bathymetric data and due to non-standardized nomenclatures and terminology used on charts, "the 7th International Geographic Congress (1899) formed a commission to standardize nomenclature and also produce and publish a global bathymetric chart". With the chairmanship of Prince Albert I of Monaco, the first edition of the General Bathymetric Chart of the Ocean (GEBCO) was produced and published in 1905. GEBCO has grown tremendously since the beginning of the 20th century transitioning from initial paper charts to the current freely available 3 dimension digital bathymetric chart of the ocean albeit at low resolution.

In the recent past, the Nippon Foundation - a Japanese non-profit organization - has supported the development and improvement of GEBCO. In this regard, during the Forum for Future Ocean Floor Mapping held in Monaco in July 2016, GEBCO and Nippon Foundation joined forces to establish the Seabed 2030 Project - now under the auspices of International Hydrographic Organization (IHO), Intergovernmental Oceanographic Commission (IOC) and GEBCO - an international collaborative effort to facilitate the complete mapping of the world ocean by 2030 (IOC, 2017). Seabed 2030 Project had been a long time coming and was borne of the fact that only a paltry 15% of the world ocean was/is covered by publicly available high-resolution bathymetry data. Our planet Earth's global ocean seafloor topography is far less known than the surfaces of other planets in our solar system including Mars and the Moon. Comparatively, Mars and the Moon are fully mapped to "better spatial coverage and very high resolutions" and remarkably at extraordinary costs. Despite the considerable effort over many years to map the oceans seafloor, it is a pity that a huge swath of our own planet's seafloor remains un-mapped in the 21st century.

Seabed 2030 Project seeks to synergize and valorize the efforts of governments, industry, research, and academia in the collection, assimilation and compilation of bathymetric data in order to develop and produce a definitive, high-resolution bathymetric map of the entire world ocean by 2030. This ambitious project's mission is to "empower the world to make policy decisions, use the ocean sustainably, and undertake scientific research that is informed by a detailed understanding of the global seafloor". It is estimated that one research vessel fitted with modern equipment (e.g. a multibeam echosounder) would take over 900 years to map the entire 140 million square miles of the entire global seafloor including the shallow waters (0 – 200 m). In this regard and due to the high costs associated with bathymetric mapping, Seabed 2030 Project seeks to create a pool of several research vessels from different nations and institutions (both public and private) and partition the global seafloor into manageable regions. If 100 vessels were to be involved, the ~900 years can easily be reduced to ~10 years. Kenya's effort in this regard is boosted by the KMFRI research programme on board RV Mtafiti (Fig. 2). Seabed 2030 Project also seeks to tap into crowd-sourcing, citizen science and vessels of opportunities by seeking partnerships with private vessels on transit and operating deep sounding equipment. Seabed 2030 Project supports the sustainable development goals (SDG) especially SDG 14 on life under water. It has also fortunately, coincided with the United Nations Decade of Ocean Science for Sustainable Development therefore creating a new impetus and focus coupled with the heightened interest in the largely un-tapped Blue Economy.

Fig.2: RV Mtafiti entering the Kilindini Harbour of Mombasa after a typical cruise of plying the coastal waters of Kenya. Photo credit KMFRI (2018)

Kenya through its research vessel (RV) Mtafiti has embarked on EEZ-wide survey entailing fish acoustics and single-beam bathymetric data collection. Figure 3 shows KMFRI scientist at work in a recent research cruise on board RV Mtafiti. The data collected would assist in further understanding and precise estimation of fish biomass and abundance that would allow for data-based/backed fishing in the deep sea. Singlebeam bathymetric data are equally important but not up to level with otherwise high-resolution multibeam bathymetric data being envisioned for Seabed 2030. Kenya therefore will still have to seek advanced equipment notably a multibeam survey equipment, a hydrographic-suited or a multi-discipline research vessel for the same and continue to build capacity to supplement that which is already available. Kenya has taken vital steps towards fully understanding its ocean, however, further steps would form a basis for increased knowledge and optimization for the benefit of the Blue Economy (Obura *et al.,* 2017).

Fig. 3: KMFRI researchers on board RV Mtafiti prepare to cast plankton net into the Indian Ocean (Photo Credit by MK Osore)

Kenya's desire to become a strong maritime nation was further demonstrated in November 2018 when it hosted the 1st Sustainable Blue Economy Conference in Nairobi (SBEC, 2019). To become a strong maritime nation requires sound knowledge of the adjacent ocean, its floor and what it entails. Furthermore, Kenya has become a member of the United Nation Security Council (UNSC), a coveted slot with relevance not only to the Nation of Kenya, but also the WIO region at large. As President Uhuru Kenyatta said in his final pitch for the UNSC seat, "Kenya's win will advance the regional and Pan-African agenda of global peace, solidarity and multilateralism". Kenya, the WIO region and Africa at large can therefore leverage on this position to advance collaborative research within the Indian Ocean as the world seeks to achieve a 100% coverage of the global seafloor by 2030. Within the Commonwealth Charter, Kenya has been nominated as a champion for blue economy.

The Figure 1 shows the expansive Indian Ocean currently covered by a paltry 2% by publicly-available high-resolution multibeam bathymetry data. The data as shown in the legend has been collected by various institutions including the Geological Institute, Russian Academy of Sciences (GINRAS), Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Kenya Marine and Fisheries Research Institute (KMFRI), United Kingdom Hydrographic Office (UKHO), National Aquatic Resources Research and Development Agency (NARA) of Sri Lanka, Royal Netherlands Institute for Sea Research (NIOZ) and others collated by data repositories including the Marine Geoscience Data System (MGDS) and National Centers for Environmental Information (NCEI) from various data contributors.

Among the direct and low-lying tangible benefits of high-resolution bathymetric maps would be the maritime trade. This would be occasioned by increased maritime traffic underpinned by high resolution and up-to-date navigation charts. Knowledge of the seafloor also directly allows for the understanding of its geological history and would provide a gateway for exploration of otherwise un-tapped minerals, oil, and gas. However, in the context of unlocking the full potential of the Blue Economy, a complete global and high-resolution bathymetric map would unlock otherwise unknown and untapped opportunities for public-private-academic partnerships and the Blue Economy entrepreneurship (Rayner, 2019a; 2019b). The success of Seabed

2030 Project will also lead to a global and a consolidated and publicly available data sources for global bathymetry and ocean observation data to support future business endeavors and natural resource exploration. By joining forces, the map of our world's oceans seafloor can be achieved. The Seabed 2030 initiative seeks to tap into efforts of individual nations and private entities to contribute data. Seabed 2030 is therefore a rallying global call to action in this massive (yet very vital) undertaking that can only be achieved through cooperation and collaboration at the local, regional and global scales.

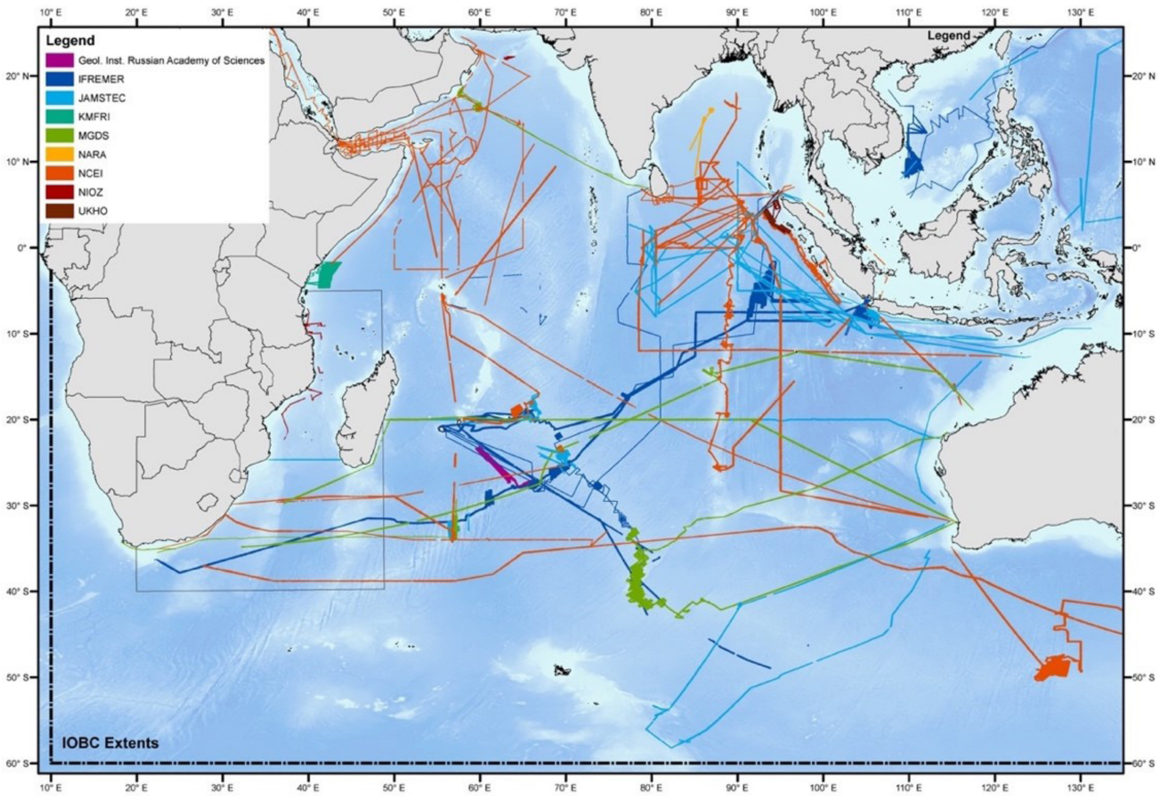

Fig. 4: Map of the Indian Ocean region showing transects of major cruise undertaken by various research programmes and institutions (Source & Credit Dr. Rochelle Wigley, 2018)

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