Linking ecological and social elements to sustain coral reef fisheries: A case of groupers [Epinephelidae] in Mafia Island, Tanzania

Koblinger mellom økologiske og sosiale dimensjoner i sikring av bærekraftig korallrevfiskerier – Et case-studium av groupers [Epinephelidae] i Mafia Island, Tanzania

Philosophiae Doctor (PhD) Thesis

Lydia Gaspare Kanyairita

Department of International Environment and Development Studies, Noragric
Faculty of Social Sciences
Norwegian University of Life Sciences (NMBU)

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To my

Mother

Gaudensia Gaspar Kanyairita, for love, support and encouragement always

Father

The late Gaspar Rudolph Kanyairita for the education inheritance he accorded me

and

Son

Joshua Chijioke Okon for bringing tremendous joy to my life

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Gaspare, L., Bryceson, I. & Mgaya, Y. D. (2015). Temporal and spatial trends in size, biomass and abundance of groupers (Epinephelinae) in Mafia Island Marine Park: Fishers' perceptions and underwater visual census surveys. *Fisheries Management and Ecology*, 2015, 22, 337–348

PAPER II

Gaspare, L. & Bryceson, I. (2013). Reproductive biology and fishery-related characteristics of the Malabar Grouper (*Epinephelus malabaricus*) caught in the coastal waters of Mafia Island, Tanzania. *Journal of Marine Biology*, 2013. http://dx.doi.org/10.1155/2013/786589

PAPER III

Gaspare, L., Bryceson, I. & Kulindwa, K. (2015). Complementarity of fishers' traditional ecological knowledge and conventional science: Contributions to the management of grouper (Epinephelinae) fisheries around Mafia Island, Tanzania. *Ocean & Coastal Management*, 114 (2015), 88-101.

PAPER IV

Gaspare, L. Effectiveness of a Marine Protected Area on fisheries management: Fishers' opinions in Mafia Island Marine Park, Tanzania. (Revised for *Coastal Management*)

Abstract

The study of the dynamic nature of interactions within and between social and ecological aspects of reef fisheries is increasing, in order to promote understanding and to mitigate complex changes from global pressure and local threats that undermine sustainable coastal fisheries. In Tanzania, a trial fisheries policy allowing the export of grouper/rock cod, among other fishes, was endorsed in the year 2002. The policy goals were to improve the livelihoods of coastal communities and increase fish product exports. However, studies of the sustainability of commercially targeted fish species in Tanzania are inadequate; no information is available on the ecology and biology of groupers in Tanzanian marine waters that would ensure the sustainability of the fishery. There is a paucity of empirical evidence on impacts of management practices on ecological and social aspects of grouper fisheries. In particular, there is little documentation on the perceptions of small-scale fishers of changes related to Marine Protected Areas (MPAs) as a fisheries management tool.

This study investigates linkages between ecology and social elements for sustainability of targeted finfish *Epinephelinae* (groupers) fisheries in Mafia Island, Tanzania. In particular, this study draws on insights from different knowledge sources to investigate ecological trends of groupers in a Marine Protected Area (MPA), and the biological traits of frequently caught grouper species. The aim is to gain scientific evidence to support sustainable grouper harvesting. Groupers are ecologically important as top-level predators and play a major role in structuring coral reef ecosystems. Being highly priced fish, groupers are heavily exploited for commercial purposes and for local consumption worldwide, hence they are susceptible to overfishing. This vulnerability to overfishing is exacerbated by the life history characteristics of groupers, such as longevity, late maturation and spawning aggregation behaviour.

Using histological analysis, the sexual maturity of *Epinephelus malabaricus* was examined and the relationship between fish size, gear used, and depth of capture was evaluated. Underwater visual census (UVC) results were used to assess changes in ecological traits (body size, biomass and abundance) of groupers with reference to the establishment of the Mafia Island Marine Park (MIMP), and results were compared with fishers' perceptions. Semi-structured interviews, key informants interviews, focus group discussions, direct observation and informal discussions

were used to generate information from fishers' knowledge and perceptions about the ecology and biology of groupers and management outcomes. Factors influencing fishers' perceptions of MPA input and outcomes were also documented.

Analysis of *E. malabaricus* specimens, a large grouper species frequently caught by small-scale fishers, showed that all specimens above 90 cm in size were male. Low numbers of large groupers were landed, mostly during the northeast monsoon, a period coinciding with the spawning season (September to February). Interviews with fishers and observations made indicated no sign that small-scale fishers were targeting spawning aggregation areas.

Fishers had mixed perceptions concerning changes in size of groupers in the MPA; their perceptions were inconsistent with results from the UVCs which show no changes in size. Perceptions related to changes in abundance of groupers were consistent with data from the UVCs, both indicating a decrease. This observation encourages reconciling information from resource users with conventional scientific data to support effective management. A decrease in abundance of groupers in both no-take zones (NTZs) and specified-use zones (SUZs) was observed. This difference could be explained, among other reasons, as a detrimental effect of fishing.

The study also found that fishers' ecological knowledge and conventional scientific knowledge (CSK) complement one another. Fishers provided information on the dynamics and patterns of grouper utilization in Mafia, habitat preferences, and feeding habits. This information coincides with data from conventional knowledge. Fishers also provided information which is new to CSK, including fishing locations and environmental threats facing groupers in the wild. An area where fishers' knowledge and CSK did not coincide relates to spawning aggregations. The disagreement may be because both fishers and scientists have limited knowledge of deeper areas of Mafia where groupers are likely to spawn. Besides, fishers lack knowledge of spawning seasons and sex differentiation of groupers. The findings suggest that further collaborative research between fishers and scientists would enhance mutual learning.

Fishers' area of residence and fishing gear operated were found to influence their perceptions of MPA outcomes. Juani fishers felt more impacted by the MIMP than those from Kiegeani, due to the restriction of pull-net fishing which is an important type of gear for Juani fishers. Fishers' involvement in MPA planning and implementation increased the likelihood of perceiving positive effects of the MPA on fishers' own fishing activities. However, their involvement in enforcement and local level awareness of MPA regulations did not enhance acceptance of the MPA in the two communities assessed. Lack of access and user rights to productive fishing grounds and gear restrictions are factors responsible for the ongoing conflict between the MIMP and fishers.

The results of the study indicate that linking ecological and social aspects of commercially targeted fish resources would contribute to the successful implementation of the ecosystem approach to fisheries at local level. The study shows that reconciling information from different sources enhances the sustainable utilization of fisheries resources. The most important contributions of this thesis include the evidence about size at first maturity of *E. malabaricus*, the complementarity of fishers' ecological knowledge and CSK on the ecology and biology of groupers, and the value of fishers' perceptions on the outcomes of changes in management practices. The study recommends that integration of fishers' knowledge and conventional knowledge would improve the participation of local communities in the management of reef fisheries resources. The sharing of information and understanding different viewpoints of fishers and western trained managers and scientists, would result in a common forum for discussing problems related to fisheries and the management of MPAs.

Sammendrag

Globalt press og lokale trusler medfører komplekse endringer som undergraver bærekraftige kystfiskerier. For en bedre forståelse og begrensning av disse endringene er det nå en økning i forskningen på den dynamiske interaksjonen både innenfor og mellom sosiale og økologiske aspekter av rev-fiskerier. I Tanzania ble det i 2002, på prøvebasis, godkjent en fiskeripolitikk som tillater eksport av blant annet Epinephelinae (en gruppe abborfisker) og morider. Imidlertid er forskningen på bærekraftigheten hos fiskearter som har blitt gjenstand for kommersielt fiske mangelfull, og derfor finnes det ingen informasjon om økologien og biologien til Epinephelinae i tanzanianske havområder som kan bidra til fiskeriets bærekraftighet. Det er få empiriske bevis for hvordan forvaltningspraksis påvirker økologiske og sosiale aspekter av Epinephelinae-fiskerier, og spesielt småfiskeres oppfatning av endringene rundt marine verneområder (MPA-er) er lite dokumentert.

Denne studien forsker på sammenhenger mellom økologiske og sosiale elementer som påvirker bærekraftigheten for utvalgte Epinephelinae-fiskerier ved Mafia-øya i Tanzania. Mer konkret bruker denne studien informasjon fra forskjellige kunnskapskilder for å undersøke økologiske trender hos Epinephelinae i et marint verneområde samt de biologiske trekkene ved ofte fangede Epinephelinae-arter. Målet er å finne vitenskapelige bevis som understøtter bærekraftig fangst av Epinephelinae. Denne fisketypen fyller en viktig økologisk rolle som topprovdyr og er derfor viktige for korallrevenes økosystemer. Men ettersom Epinephelinae har høy salgspris, er fiskearten utsatt for overfiske på grunn av sterk kommersiell utnytting og lokalt forbruk verden over. Denne sårbarheten for overfiske blir forsterket av de spesielle egenskapene i Epinephelinaes livsløp, slik som lang levetid, sen modning og gyteansamling.

Ved hjelp av histologisk analyse ble *Epinephelus malabaricus'* seksuelle modenhet undersøkt og sammenhengen mellom fiskestørrelse, fiskeutstyr og fangstdybde evaluert. Resultater fra visuell undervannstelling, eller UVC (engelsk: *underwater visual census*), ble brukt for å vurdere endringer i Epinephelinaes økologiske egenskaper (kroppsstørrelse, biomasse og tallrikhet) i forbindelse med opprettelsen av Mafia Island Marine Park (MIMP), og resultatene ble sammenlignet med fiskernes oppfatninger. Semistrukturerte intervjuer og intervjuer med nøkkelinformanter, fokusgruppesamtaler, direkte observasjoner og uformelle diskusjoner ble

brukt for å samle informasjon basert på fiskernes kunnskap og oppfatninger om Epinephelinaes økologi og biologi og om forvaltningsresultater. Faktorer som påvirker fiskernes oppfatning av MPA-bidrag og resultater ble også dokumentert.

Analyser av *E. malabaricus*-eksemplarer, en stor Epinephelinaes-art som ofte blir fanget av småfiskere, viste at alle eksemplarer større enn 90 cm var hannkjønn. Et lavt antall store Epinephelinae ble fanget, hovedsakelig under nordøstmonsunen, som sammenfaller med gytesesongen (september til februar). Intervjuer med fiskere, samt observasjoner, ga ingen grunn til å tro at småfiskere konsentrerte seg om gyteansamlingsområder.

Fiskerne hadde ulike oppfatninger angående Epinephelinaes størrelsesendringer i verneområdet. Deres oppfatninger samsvarte ikke med resultater fra undervannstellingene som ikke viste noen endring i størrelse. Oppfatninger om endringer i antallet Epinephelinae samsvarte med data fra undervannstellingene: begge tydet på en nedgang. Denne observasjonen fremhever viktigheten av å sammenstille informasjon fra ressursbrukere med konvensjonelle vitenskapelige data for slik å understøtte en effektiv forvaltning. En nedgang i antallet Epinephelinae både i nullfiskesoner og soner med fiskebegrensninger ble observert. Denne forskjellen kan forklares som blant annet skadelige følger av fisket.

Studien viste også at fiskernes økologiske kunnskap og konvensjonell vitenskapelig kunnskap (CSK, fra engelsk: *conventional scientific knowledge*) utfyller hverandre. Fiskerne bidro med informasjon om dynamikk og mønster for utnyttelse av Epinephelinae i Mafia, foretrukket habitat, og matvaner. Denne informasjonen sammenfaller med data fra konvensjonell kunnskap. Fiskerne bidro også med informasjon som er ny innen CSK, inkludert fiskesteder og miljøtrusler Epinephelinae møter i naturen. Et område hvor fiskerens kunnskap og CSK ikke sammenfalt var gyteansamlinger. Uenigheten kan skyldes at både fiskere og forskere har begrenset kunnskap om de dypere områder av Mafia hvor Epinephelinae sannsynligvis gyter. Dessuten mangler fiskerne kunnskap om gytesesonger og kjønnsdifferensiering av Epinephelinae. Disse funnene tyder på at videre samarbeid mellom fiskere og forskere vil fremme gjensidig læring.

Fiskeres bosted og fiskeoppstyr viste seg å påvirke deres oppfatning av verneområdenes resultater. Juani-fiskere følte seg mer berørt av MIMP enn fiskere fra Kiegani, noe som skyldes restriksjoner på garnfiske som er en viktig metode for Juani-fiskere. Fiskernes deltakelse i planleggingen og implementeringen av det marine verneområdet økte sjansen for at de skulle se at verneområdet også påvirket deres egne fiskevirksomheter positivt. Imidlertid førte ikke deltakelsen i håndheving av verneområdets regelverk og bevisstgjøring omkring dette til at verneområdet ble mer akseptert i de to samfunnene som ble evaluert. Manglende tilgang til produktive fiskeområder og bruksrettigheter til disse, samt utstyrsrestriksjoner, er årsakene til den pågående konflikten mellom MIMP og fiskerne.

Studiens resultater tilsier at det å se de økologiske og sosiale aspektene ved kommersielt utnyttede fiskeressurser i sammenheng kan bidra til en vellykket implementering av økosystem-tilnærmingen hos lokale fiskerier. Studien viser at en sammenstilling av informasjon fra forskjellige kilder styrker den bærekraftige utnyttelsen av fiskeriressurser. Blant denne avhandlingens viktigste bidrag er beviset på *E. malabaricus'* størrelse når den først blir moden, hvordan fiskernes økologikunnskap og konvensjonell vitenskapelig kunnskap om Epinephelinaes økologi og biologi utfyller hverandre, og verdien av fiskernes forståelse av resultatene etter endringer i forvaltningspraksis. Studien anbefaler en integrering av fiskernes kunnskap og konvensjonell kunnskap fordi det ville styrke lokalsamfunnenes deltakelse i forvaltningen av rev-fiskeriressurser. Informasjonsutveksling og en forståelse for de forskjellige synspunktene hos fiskere, vestlige forvaltere og forskere, ville føre til et felles diskusjonsforum for problemstillinger rundt fiskerier og forvaltningen av marine verneområder.

PART ONE: SUMMARY

1 Introduction

Marine fisheries resources contribute to incomes and food security for the millions of people living in coastal communities in developing countries (FAO 2008-2015). The fisheries sector is an important source of employment and high quality food in terms of proteins, fats and oils, vitamins and minerals, which are especially important to children and pregnant women, as well as to urban and export markets. However, many coastal fisheries are facing challenges in sustaining fishing livelihoods due to overutilization, lack of alternative livelihoods, weak governance, and other biophysical influences (e.g. climate variability) (Chuenpagdee et al. 2005; Andrew et al. 2007; Salas et al. 2007).

In Tanzania, marine waters constitute territorial waters and the Exclusive Economic Zone (EEZ), with areas of 64,000 km^2 and 223,000 km^2 respectively. The total annual marine fish harvest is approximately 66,000 tons (Jacquet et al. 2010). Marine fisheries in territorial waters are mainly small scale, referring to fishing practices that are

> … dominated by fishers using simple fishing gear, such as small nets, traps, lines, spears, and hand-collection methods and targeting multi-species. They have limited capacity for processing, storage and transportation of their product, which makes for high rates of post-harvest loss. There is a complex and dynamic fleet interaction, there is competition among the fishers and between fleets, there is a collection of catch data for the main target species which in most cases is doubted as reliable, management[1] control in place is largely input controls such as size limits, gear restrictions, closed seasons, closed areas and fishing permits. (Berkes et al. 2001)

Small-scale fisheries are estimated to account for 98 % of total Tanzanian fish production, 1.3 % of GDP and 9.9 % of fish exports worth an estimated US$12.4 million (URT 2009). While most of those exports come from lake fisheries, small-scale fisheries (along with agriculture)

[1] Management is the "art of taking measures affecting a resource and its exploitation with a view to achieving certain objectives, such as the maximisation of the production of that resource" (FAO 2011-2015).

constitute a significant portion of food, income, and employment for those who live along the coast. Fishing provides a major food source for coastal communities, accounting for almost 60 % of animal protein consumed (JICA 2005 in MLDF 2014). It has been estimated that there are 36,321 small-scale fishers operating in marine coastal waters off Tanzania, using traditional fishing vessels, mainly canoes, outrigger canoes, planked wooden boat and those who operate on foot without vessels (URT 2009). More than 500,000 coastal inhabitants derive their economic livelihood from fisheries and related activities such as fish processing and marketing (URT 2009).

Marine waters along the coast of Tanzania are endowed with more than 500 fish species (Jiddawi & Öhman 2002). The majority of targeted fish species by small-scale fishers are *Epinephelidae*, *Lutjanidae* and *Lethrinidae* (Mgaya et al. 1999). Small-scale fishing for demersal fish is concentrated on coral reefs, muddy/sandy and seagrass beds due to easy accessibility and higher productivity. Local fisheries are open access, based on common property rights in the sense that any individual wishing to go fishing can do so. Fishing boats are required to be licensed and fishers must have a fishing license from the local authority; this also applies to migrant fishers who come from outside a local community. These arrangements have allowed many coastal residents to participate in small-scale fishing.

Fish availability is of great importance to poverty eradication among coastal communities at the local level, as well as contributing to foreign currency earnings at the national level. Population growth along the coast, as well as growing export demands for certain marine products, are placing increasing pressure on fisheries and underlying habitats. Increase in fishing pressure has significant effects on the abundance and biomass of reef fishes (Russ & Alcala 1989; Kamukuru et al. 2004), as well as on coastal communities who depend on the fishery. Near-shore fish resources in some areas of Tanzania have been heavily exploited by fishers using simple fishing vessels and gear, causing problems of localized overfishing[2] (Jury et al. 2010; Katikiro 2014). Problems of dwindling near-shore fish resources have been exacerbated by a

[2] See Pauly (1994) for definition of overfishing

lack of proper management plans, and weak enforcement (Jiddawi & Öhman 2002; Van der Elst et al. 2009).

For many decades, MPAs have been promoted as an efficient and inexpensive way of managing coastal marine fisheries against unregulated fishing activities (Alcala & Russ 1990; Roberts & Polunin 1993). A Marine Protected Area is defined by the International Union for Conservation of Nature (IUCN) as "Any area of the intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher and Kenchington 1992: 7). The aims of MPAs are to preserve biodiversity and protect spawning or nursery grounds of commercially harvested species. Groupers are among the most important commercial reef fish, with more than fifty species recorded in the western Indian Ocean (Heemstra & Randall 1993).

Globally, groupers are heavily exploited for commercial purposes because of high prices offered by the international market (Randall 1987; Sadovy de Mitcheson et al. 2013). Hence they are susceptible to overfishing and some species are listed by the IUCN as threatened or near threatened, due to increased fishing pressure. Among the life history characteristics that contribute to their susceptibility are slow growth, delayed reproduction, large size, spawning aggregations[3] and longevity (Sadovy & Colin 1995). Some species are sequential hermaphrodites, beginning life and reproducing as females before changing sex to males at an older age (Young & Martin, 1982). Increased fishing pressure targeting mature fish is likely to selectively remove males, thereby adversely affecting the reproductive capacity of the population (Shapiro 1987; Mackie 2000). In some parts of the world, for example the Caribbean, groupers have been overexploited (Aguilar-Perera 2006; Sadovy de Mitcheson et al. 2013). Decline in abundance, size of fish, landings and catch per unit effort, disappearance of spawning aggregations, and changes in species diversity have been reported in different parts of the world due to the failure of conventional fisheries regulations (Sadovy 1994; Huntsman &

[3] A spawning aggregation is "a repeated concentration of conspecific marine animals, gathered for the purpose of spawning, that is predictable in time and space. The density/number of individuals participating in a spawning aggregation is at least four times that found outside the aggregation. The spawning results in a mass point source of offspring" (Domeier 2012: 4).

Schaaf 1994; Chiappone et al. 2000). However, there is little information from scientific and local user perspectives on the status of the *Epinephelidae* population trends in Tanzania.

This study investigated the biology of frequently caught groupers, and examined the complementarity of fishers' knowledge and conventional scientific knowledge about the ecology and biology of groupers, in order to elucidate their vulnerability to fishing. The research further examines fishers' opinions on the performance of the MPA in order to elucidate its effectiveness as a management tool governing the utilization of fisheries resources. This study aims to contribute to closing the knowledge gap by interlinking the fields of natural science and social science, as well as combining scientific and local knowledge for sustainable small-scale fisheries utilization.

1.1 Background to the study

Responding to global demand for fish and earnings from the export of marine finfish, in 2002 the Tanzanian Fisheries Department introduced a trial lifting of the ban on the export of marine finfish from territorial waters. The permit was granted to a few companies on the basis of a verbal understanding to purchase finfish from small-scale fishers. These companies proceeded to purchase finfish and the exercise involved improving and providing essential equipment to local fishers, such as nets, boats, outboard engines, icing plants, vehicles, storage facilities and ice on a daily basis. Although positive potentials from the licensing of marine finfish exports were foreseen, the government wished to monitor the effects of the trial export fishery in order to ensure social and ecological sustainability.

Furthermore, various stakeholders, including the Mafia Island Marine Park and the researchers Anderson and Ngatunga (2005), expressed concern regarding the species and size of fish exported, increased fishing pressure around shallow, near-shore coral reef habitats and vulnerable species, and a reduction in the availability of fish for domestic consumption both in Mafia and Dar es Salaam. They stated that some species with high tourism and conservation value would be particularly vulnerable to overfishing, including *Epinephelus* and *Plectropomus*. Mafia Island was identified as one of very few sites in Tanzanian waters where these species are still relatively abundant, compared to many Asian countries where they have become locally extinct due to overutilization for their high value in the live fish food trade (Sadovy de Mitcheson et al. 2013).

A mid-term review carried out by the Ministry of Natural Resources Programme (MNRP) in 2004, recommended to the Ministry of Natural Resources and Tourism and the Royal Norwegian Embassy that a study should be conducted regarding the lifting of the ban on the export of marine finfish in Tanzania. In 2006 an interdisciplinary team of researchers conducted the MNRP-TAN0092 project to investigate and monitor the positive and negative ecological, economic and social effects of the trial change in fisheries policy to allow the export of marine finfish. The research goals of the study were to address key aspects of fisheries science, biodiversity issues, and ecological, economic, social, and legal aspects related to any positive and negative changes induced by the trial change in fisheries policy.

The MNRP-TAN0092 project focused on the case of Mafia Island, where the first fish processing factory targeting the international export market was established. The study utilized the conceptual framework of ecological and social resilience and vulnerability developed by Berkes & Folke (1998), Berkes et al. (2003) and Anderies et al. (2004), as an analytical approach in order to analyze the interlinkages between various ongoing processes. Areas of investigation included (i) a biological-ecological study, (ii) a participatory fish stock assessment, (iii) a socio-economic study, and (iv) a socio-cultural study. The studies concluded that the Tanzanian Government's decision to allow the export of finfish on a trial basis was wise; however, there were also a number of vulnerabilities in the ecological and social systems that required careful investigation and monitoring over time (Bryceson et al. 2006). The present study therefore used the MNRP-TAN0092 work as a baseline for assessing the interlinkages in grouper fisheries, using a multiplicity of methods to fully integrate fishers' perceptions and conventional methods in order to understand the linkages between social and ecological system of grouper fisheries. The term 'linkage' refers to the interrelationship between, or interactive aspects of various components of a social-ecological system.

1.2 Rationale for this study

Studies on the sustainability of commercially targeted reef fisheries in Tanzania are inadequate. Since the inception of the MIMP in 1995, several studies have been conducted to monitor the ecological (Garpe & Öhman 2003; Kamukuru et al. 2004; Garpe & Öhman 2007) and social (Francis et al. 2002; McClanahan et al. 2008; Mwaipopo 2008; Benjamisen & Bryceson 2012; Moshy et al. 2013; Kincaid et al. 2014) performance of the park. However, fishers' ecological knowledge and perceptions on changes in targeted fish species have received less attention. Due to ignoring fishers' knowledge, the process of integrating conservation, sustainable fisheries resource use, and development has remained contradictory and poorly addressed in Mafia Island. There is a clear information gap regarding the linkages between ecological aspects, biological traits, fishing practices and management approaches of grouper fisheries in Tanzania.

This study focuses on developing a scientific understanding of the ecology and biology of a targeted finfish family (*Epinephelidae* − groupers) in order to elucidate their vulnerability to fishing. It simultaneously examines issues related to the effectiveness of management approaches in the Mafia Island Marine Park. The results contribute to closing existing knowledge gaps in interlinking natural and social sciences, as well as combining conventional scientific and traditional knowledge, in order to contribute towards sustainable utilization of coastal fisheries resources. According to Pomeroy and Berkes (1997), the complementarity of traditional and scientific knowledge makes co-management of natural resources stronger than either community-based or government management systems alone.

1.3 Thesis structure

The thesis is divided into two parts. Part A presents the theoretical background of linking ecological systems to social mechanisms for building sustainability in small-scale fisheries in tropical developing countries. This part is divided into five sections. Section one is an introduction which presents the background, rationale for the study, and its objectives. Section two presents a review of conceptual and theoretical perspectives for the study, and a framework for understanding the interlinkages between ecological and social elements for sustainability of groupers. The third section describes various data collection methods for both ecological and social studies, and the research methods utilized in this study. Section four presents a synthesis of the findings on biological and ecological aspects of groupers in relation to fishers' knowledge and practices, effectiveness of management practices, and implications for the sustainability of reef fisheries. The final section provides conclusions and recommendations. Part B of the thesis consists of four papers from individual studies based on the following specific objectives.

1.4 Objectives of the study

The overall objective of the study was to investigate linkages between ecological and social elements for building sustainability of grouper fisheries in Mafia Island, Tanzania. The specific objectives and research questions addressed by the respective individual papers are:

1) To investigate the temporal changes in abundance and biomass of groupers at five selected sampling sites with varying levels of protection in the Mafia Island Marine Park.

   Research questions:

   a) How do fishers' perceptions of changes in size and abundance of groupers compare with data from the Underwater Visual Census, with reference to conditions before-and-after establishment of the park?
   b) Is there any association between fishers' perceptions of changes in grouper abundance and fishers' personal attributes (e.g. area of residence, age, gear, source of income, fishing experience)?
   c) What is the effect of no-take zones (NTZs) on the density, biomass and diversity of species of groupers compared to specified-use zones?

2) To investigate the reproductive biology, size structure and maturity of *Epinephelus malabaricus* (a grouper species caught mostly by small-scale fishers), and how life history traits associate with fishing practices, in order to explore any evidence and effects of fishing pressure.

Research question:

How do fishing activities in Mafia associate with life history traits of *E. malabaricus* in terms of the following?

a) Sexual maturation based on the histology of the gonads?
b) Size structure, size at first maturity and sex ratio?
c) Spawning seasons?

3) To investigate how fishers' ecological knowledge compares with conventional scientific knowledge on the sustainable utilization of grouper fisheries, with particular focus on the biology, ecology and management of groupers.

Research questions:

a) What are the dynamics and patterns of grouper utilization in Mafia?
b) How does fishers' knowledge of the ecology and biology of groupers compare with, or complement conventional scientific knowledge?

4) To examine how management practices have contributed to the sustainable utilization of small-scale fisheries.

Research questions:

a) Is there any association between fishers' perceptions of MPA input and outcomes, and fishers' personal attributes such as area of residence, age, source of income, fishing experience and type of fishing gear?
b) To what extent has the MIMP achieved its objectives of promoting sustainable resource use, rehabilitation of damaged ecosystems, and involvement of local residents in the development and management of the park?

2 Concepts and theoretical perspectives

In this thesis, fisheries data, and bio-ecological and social-cultural issues supporting sustainable coastal fisheries are analyzed at the local level. Various concepts are used in relation to the assessment[4] of grouper fisheries, which are elucidated in the following sub-sections.

2.1 Sustainability of reef fisheries

This thesis aims to contribute to efforts to enhance sustainable development of coastal fisheries, which is defined according to WCED (1987: 16) as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

Historically, the management of natural resources was supported by the theoretical idea of determining a maximum sustainable yield, defined by Hilborn (2005: 248) as the “largest equilibrium yield (or catch) that can be taken from a fish stock under existing environmental conditions without causing a decline in the resource available in future years”. However, a growing body of evidence indicates that a focus on sustainable yield emphasizes a physical output while neglecting the underlying natural fluctuations and processes, health of ecosystems, and integrity of ecological interactions (Costanza & Daly 1992; Goodland 1995; Charles 2004; Hilborn 2005). It is now widely recognized that sustainability must be viewed in an integrated manner that involves maintaining and enhancing the wellbeing of ecological, social, economic and cultural systems (Garcia 1997; Hilborn 2005). For example, The World Conservation Strategy defines sustainability as “meeting basic human needs while maintaining essential ecological processes and life-support systems, preserving genetic diversity, and ensuring sustainable utilization of species and ecosystems” (IUCN/UNEP/WWF 1980).

Regarding small-scale fisheries, sustainability involves applying a precautionary approach to guard against undesirable outcomes, which include not only overutilization of fishery resources and negative environmental impacts, but also unacceptable social and economic consequences (Berkes & Folke 1998). This new approach is termed the ‘ecosystem approach to fisheries

[4]‘Assessment’ refers to the evaluation of the status of various indicators that determine the state of small-scale fisheries.

management' (EAFM), defined as "managing fisheries in a manner that addresses multiple needs and desires of society, without jeopardizing options for future generations, to benefit from the full range of goods and services provided by marine ecosystems" (FAO 2003).

Proponents of EAFM present convincing arguments that conventional approaches to fisheries management (e.g. the maximum sustainable yield − MSY) have not worked well, especially for small-scale fisheries in the developing world that participate in a multi-species fishery (Lauck et al. 1998; Berkes 2003; Pikitch et al. 2004; Pomeroy et al. 2010). Pikitch et al. (2004) affirm that management of fisheries based on single-species model has ignored ecosystem components such as habitats and predator-prey interactions.

An ecosystem-based approach to fishery management is now considered a necessary tool for all fisheries systems (Cissé et al. 2014); however, adoption and implementation of the approach is a major issue for developing countries, due to poverty and other socio-economic challenges (Mathew 2003). The necessity of EAFM in developing countries stems from its strength in taking into account the complexity of marine and coastal ecosystems, and considering fishers as part of the ecosystem (Mathew 2003). EAFM places major emphasis on addressing the effects of fishing on fish stocks, socio-economic needs of resource users, as well as collaborative approaches to management processes and decision making (Berkes et al. 2001; Mathew 2003).

2.2 Social and ecological linkages in reef fisheries

Linked social and ecological systems research in coastal fisheries is rooted in a shift in the natural resource management paradigm from the biological-centered approach to the ecosystem approach to fisheries (described above) which advocates that social and ecological systems are linked and complex (Berkes & Folke 1998; Bellwood et al. 2004; Ommer et al. 2012). This theory was proposed essentially to reverse the order of management priorities − to start with the ecosystem rather than the target species, and include people in the system instead of regarding them as separate from the natural environment (Link 2002).

A social-ecological system (SES) refers to a system composed of social systems and ecological systems interacting with each other in different ways through temporal, spatial and organizational scales (Anderies et al. 2004). 'Social systems' (that are of primary concern for this thesis) refer to human elements and their knowledge and perceptions concerning the marine environment, fisheries regime systems, fisheries resources, and their worldviews and ethics (values). The term 'ecological system' is used to refer to the fish (groupers) and their natural habitats (Berkes & Folke 1998).

Berkes and Folke (1998) assert that there is no single, universally accepted way of formulating the linkages between social and ecological systems. However, various studies in the literature have found that the way societies interact with nature is influenced by social, economic, cultural, and political factors (Berkes & Folke 1994; Cinner et al. 2009; Pollnac et al. 2010). Scientists from different schools of thought, such as human ecology and ethno ecology (among others), have addressed the relationship between humans and nature (Davidson-Hunt & Berkes 2003). In this thesis I borrow insights from these fields in order to understand the linkages between social and ecological elements in grouper fisheries.

Linkages between the social and ecological aspects of a fishery system are often analyzed by means of the livelihoods approach, and studying management institutions and systems of knowledge (Berkes & Folke 1998; Allison & Ellis 2001; Cinner et al. 2009). The most popular and perhaps most widely accepted system of knowledge is that of conventional scientific knowledge (CSK), which refers to observations by fishery scientists and managers using conventional 'hard' data derived from scientific studies and theoretical interpretations (Mackinson 2001; Berkes et al. 2000). However, different societies may have different understandings of social and ecological processes and phenomena. In this thesis, social and ecological elements are linked by resource users' knowledge and perceptions, which are a fundamental source of change in management regimes.

Researchers and practitioners across many disciplines now recognize that local people's knowledge and perceptions are important in the management and monitoring of ecosystem processes and functions in order to promote the sustainable use and conservation of marine resources (Warren 1996; Berkes & Folke 1998; Berkes et al. 2000; WIPO 2001; Dei et al. 2002; UNESCO 2006; Lauer & Aswani 2009; Hind 2014). Agenda 21 of the Rio Conference recognizes the role played by local communities in supporting sustainable use and conservation of marine living resources. For example, the role of traditional knowledge in promoting sustainability of small-scale fisheries is contained in Agenda 21, Chapter 17, part 74 which records that “States commit themselves to the conservation and sustainable use of marine living resources under national jurisdiction. It is necessary to: Take into account traditional knowledge and interests of local communities, small-scale fisheries and indigenous people in development and management programs” (UNCED 1992). Furthermore, Chapter 17, part 81(c) states that “the Coastal State should develop systems for the acquisition and recording of traditional knowledge concerning marine living resources and environment and promote the incorporation of such knowledge into management systems” (UNCED 1992).

2.3 Fishers knowledge and fisheries management

Fishers’ knowledge (FK) may be described using different terms such as: ‘local ecological knowledge’ (LEK), ‘traditional ecological knowledge’ (TEK) and ‘indigenous ecological knowledge’ (IEK). According to Olsson and Folke (2001), “LEK describes the knowledge held by a specific group of people about their local ecosystems. It may be a mix of scientific and practical knowledge; it is site specific, and often involves a belief component”. LEK differs from traditional ecological knowledge (TEK) in that it often lacks the dimension of historical and cultural continuity. TEK is a “cumulative body of information, beliefs and practices evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment” (Berkes et al. 2000: 1252). An analysis of many IEK systems reveals a component of local observational knowledge of species and other environmental phenomena, a component of practice in the way people carry out their resource use activities, and a component of belief regarding how people fit into or relate to eco-systems (Berkes et al. 2000). Although these various terms have different connotations regarding the application of knowledge, they are used interchangeably in this thesis to describe the knowledge held by small-scale fishers about the ecology, biology and management of groupers.

The use of fishers’ knowledge is described as an asset for the implementation of the ecosystem approach to fisheries (EAF) because of its cost-effectiveness and complementarity with conventional scientific approaches (Johannes 1998; Berkes & Folke 1998; Garcia & Cochrane 2005). Moreover, using local knowledge provides a foundation for participatory approaches and an opportunity to access a wide range of information necessary for decision making in adaptive fisheries management (Warren 1996; Berkes & Folke 1998).

Given the calls for greater collaboration between scientists and local knowledge holders, conducting evaluations and monitoring impacts of fishing on social and ecological systems using multi-sources of knowledge are a pre-requisite for the implementation of global conventions (Thornton & Scheer 2012). However, the use of fishers' knowledge for promoting sustainable utilization of fisheries remains rather marginal and constrained by a lack of consideration in mainstream fisheries science and management, despite "being a century old" (Hind 2014: 1). According to Thornton and Scheer (2012), collaborative projects in conservation and fisheries management engaging local and traditional knowledge and science in marine environments are rare. This thesis has taken an important step in evaluating fishers' knowledge on groupers and comparing it with conventional knowledge in a Marine Protected Area (MPA) in order to add to existing knowledge and seek ways to improve fisheries management.

2.4 The role of Marine Protected Areas in sustaining reef fisheries

Coastal and marine resources worldwide are under increasing threats due to ever increasing numbers of resource users with competing interests, as well as other global threats. Resource degradation, declining fisheries, loss of key habitats (e.g. coral reefs, seagrass beds, and mangrove forests) and other related coastal and marine resources, are undermining biodiversity and the long-term sustainability of tropical marine ecosystems (Green et al. 2014). The result is escalating hardships and economic instability in regions where fisheries provide important ecosystem goods and services for coastal communities (Willmann & Kelleher 2010).

Responding to the losses, and building on opportunities to manage the resources that remain to support sustainable livelihoods, have thus become urgent conservation and development objectives in recent years (Roberts et al. 2005). In relation to supporting sustainable use and the conservation of marine living resources, Agenda 21, Chapter 17, part 85 of the Rio Conference requires that “States should identify marine ecosystems exhibiting high levels of biodiversity and productivity and other critical habitat areas and should provide necessary limitations on use in these areas, through inter alia, designation of protected areas” (UNCED 1992).

Efforts towards realizing global commitments of combatting overfishing are articulated through the establishment of ‘NTZs’. Theoretical and empirical studies suggests that NTZs can sustain reef fisheries by 1) increasing fish biomass within their boundaries; 2) protecting corals and other habitats for reef fishes from damage caused by uses such as destructive fishing practices; and 3) providing a ‘spillover’ of adult fishes close to reserve boundaries (Russ & Alcala 1996; Murray et al. 1999; Chiappone & Sealey 2000; Russ 2002; Lester et al. 2009). In addition, fishery closures may enhance the development of natural age structures of exploited species, protection of genetic variability, restoration of ecosystem integrity, and insurance against management failure (Bohnsack 1996). Some researchers claim that absolute NTZs are rare worldwide due to a lack of experience in their utility in fisheries management (Bohnsack 1996; Attwood et al. 1997; Ward et al. 2001; Roberts et al. 2005).

In developing countries such as Tanzania, many of the coastal inhabitants are subsistence fishers. The imposition of an MPA is associated with accompanying conservation policies, rules and regulations that frequently conflict with the needs and interests of local people. In this study, I utilized a mixed methods approach to understand the role of the MPA in sustaining ecological and social aspects related to grouper fisheries, in order to inform management practices.

2.5 Framework for analyzing linked social and ecological elements

This study adopts an interdisciplinary approach whereby linkages are analyzed by investigating the resource, resource users’ knowledge, and management input and outcomes in Mafia Island. I borrowed insights and analytical tools from the frameworks developed by Berkes and Folke (1998), Ostrom (2009), Ommer et al. (2012), and Kittinger et al. (2013) in order to facilitate the identification of the linkages between the status of grouper fisheries, small-scale fishers and management practices.

The key lines of inquiry within the literature are based on sustainability indicators (SIs). Sustainability indicators are markers which are used to divulge and monitor the conditions and trends in a fishery, as well as management performance in relation to the environment, targeted fish species, social conditions and the cultural context (Garcia 1997). Various SIs have been proposed in fisheries management to meet global requirements (see Garcia 1997). Indicators that are important for this study are summarized in Fig. 1 under the following interrelated components: 1) the resource units; 2) the users; and 3) the management tools. These broader elements of analysis are unpacked to obtain a lower conceptual level (Fig. 1 and Table 1). It is of vital importance to remember that the system is open to other factors, such as political and external influences, global trade and the liberalization of finfish exports, and climate change that may influence sustainability; however these additional factors are not analyzed in this study.

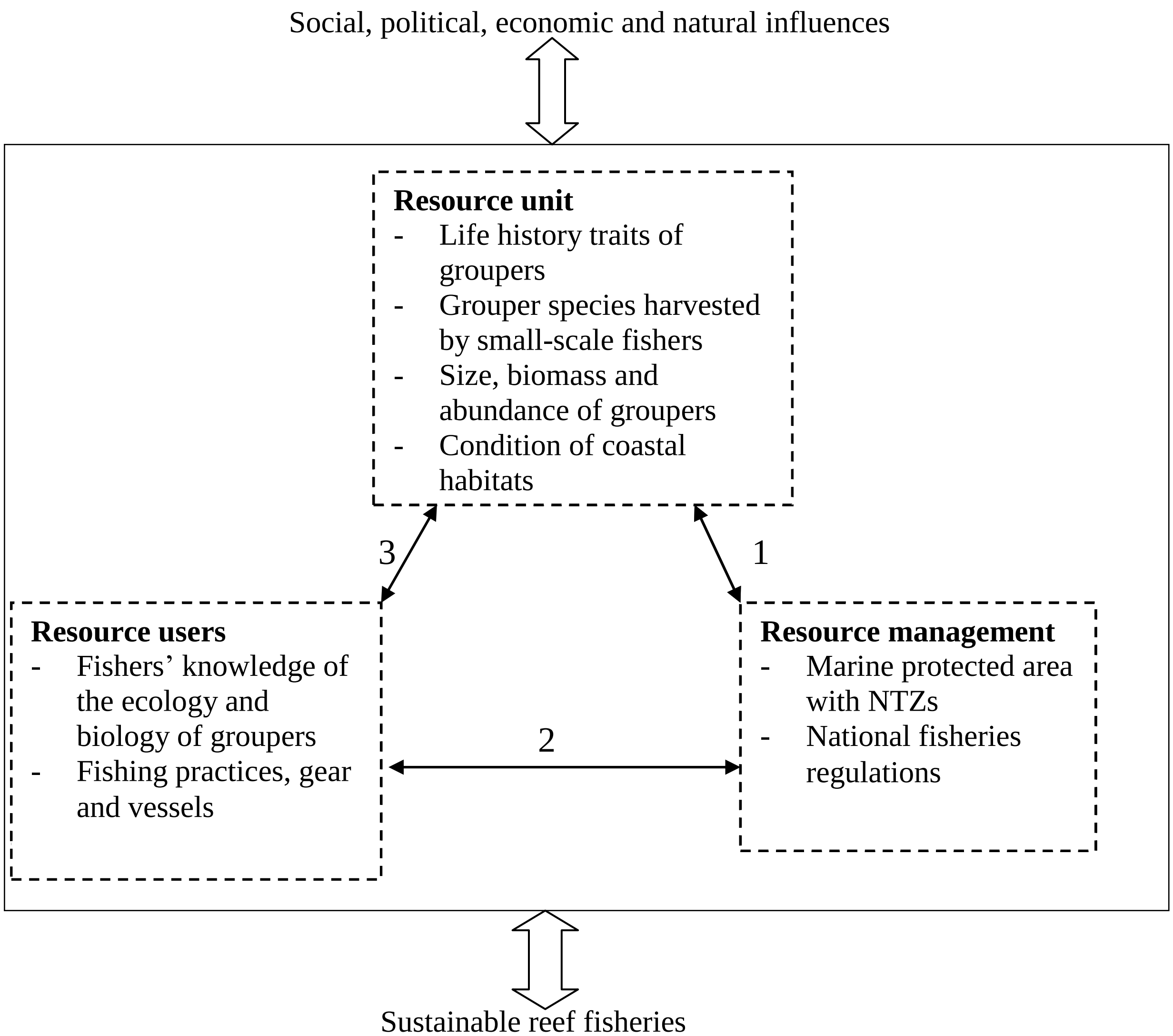

Figure 1: A framework for the analysis of ecological and social linkages for the sustainability of reef fisheries in Mafia Island, Tanzania[5]

[5] Individual studies (Paper I, II, III, and IV) are reported in Part B

Table 1: Variables in a framework (Fig. 1) for analyzing linkages between resource unit, resource management, resource users and patterns of interactions in grouper fisheries in Mafia Island

Linkage 1

i. Changes in size, abundance and biomass of groupers before and after establishment of the MIMP
ii. Abundance and biomass of groupers in NTZs and specified use zones
iii. Fish catch trends before and after establishment of the MIMP
iv. Habitat extent and quality before and after establishment of the MIMP

Linkage 2

i. Fishers' perceptions of their involvement in planning, and enforcement of the MPA regulations
ii. Social acceptance of the MPA, compliance and sanctions
iii. Gear exchange scheme
iv. Level of conflicts related to fisheries and their management

Linkage 3

i. Relationship between the size and type of fishing gear and species of groupers, their size and depth of capture
ii. Fishers' knowledge and perceptions of different aspects of grouper fisheries (e.g. knowledge of grouper feeding habit and choice of baits)
iii. Influences of fishers' personal attributes (e.g. area of residence, age, gear type, fishing experience, income source) on their perceptions of MPA outcomes

In Fig. 1, the resource units are the grouper species harvested by small-scale fishers. The management tools include the policies of the Marine Protected Area and other rules and regulations that shape resource utilization in fisheries off Mafia Island. These management tools determine incentives for, and behavior of fisheries resource users. Such users include resident and non-resident fishers, researchers, government officials, and the private sector. In understanding the dynamics of the resource unit, I investigated the ecological and biological traits of groupers using conventional scientific and social research methods. Attention was paid to understanding the life history traits of groupers (size at maturity, spawning seasons, and reproduction strategy), spatial and temporal trends in biomass and abundance of groupers; and the extent and quality of habitats within MIMP boundaries (Papers I, II, III and IV).

Regarding resource users, I focused on investigating the dynamics of resource utilization, including changes in the number of fishers, types of fishing gear, fishing locations, capacity of fishing vessels, and technological developments which may have negative or positive effects on resource utilization and management (Papers II, III, and IV). Attention was paid to various characteristics of fishers which might directly or indirectly influence patterns of utilization and local management arrangements. I investigated how contextual variables such as fishers' area of residence, age, fishing gear operated, fishing experience, and source of income may influence their perceptions of management inputs and outcomes. In a small-scale fishery setting, gear type will dictate where the principal fishing effort is spatially located in the seascape, which in turn is likely to affect the type and scale of ecological knowledge accumulated. Thus, existing knowledge and understanding of ecological systems among user groups provides a strong incentive for sustainable management of the resource.

Papers I and IV address issues related to management outcomes, using both conventional methods and fishers' perceptions. I focused on investigating how fishers perceive and respond to both ecological and social management outcomes, based on evaluative criteria in the social context, e.g. participation, enforcement, compliance, and acceptance of MPAs.

3 Methodology

A study of linking social and ecological elements in natural resources requires consideration of philosophical assumptions about the nature of reality and the question of what is knowledge and how it can be accessed. Thus both objective realities and subjective justification, which inform the use of both quantitative and qualitative research strategies, were considered to be equally important in this study. These methodological premises were chosen because of the nature of the problems associated with reef fisheries, which are multifaceted and include realist as well as social constructivist aspects. Thus, to understand the social and ecological linkages of sustainable grouper fisheries, scientific measurements were complemented by data gathered from interviews with fishers.

3.1 Study area and sampling sites

The study was carried out in Mafia Island and its small islets, which lie approximately 120 km south of Dar es Salaam and 20 km offshore from the eastern extent of the Rufiji Delta (Fig. 2). The island is about 48 km long and 17 km wide at its widest point. It has a population of 46,438 (according to the 2012 census) and an area of 413 km^2. The western side of the island is more sheltered from winds, and sedimentary materials discharged by the Rufiji River on the mainland influence water clarity. The eastern side is exposed to the winds of the Indian Ocean and has a 33 km outer fringing reef along the eastern seaboard. The continental shelf is narrow and falls to a depth of over 1,000 m within 20 km of the main island. Several reefs and extensive intertidal flats occur along the southern and southwest parts of the island.

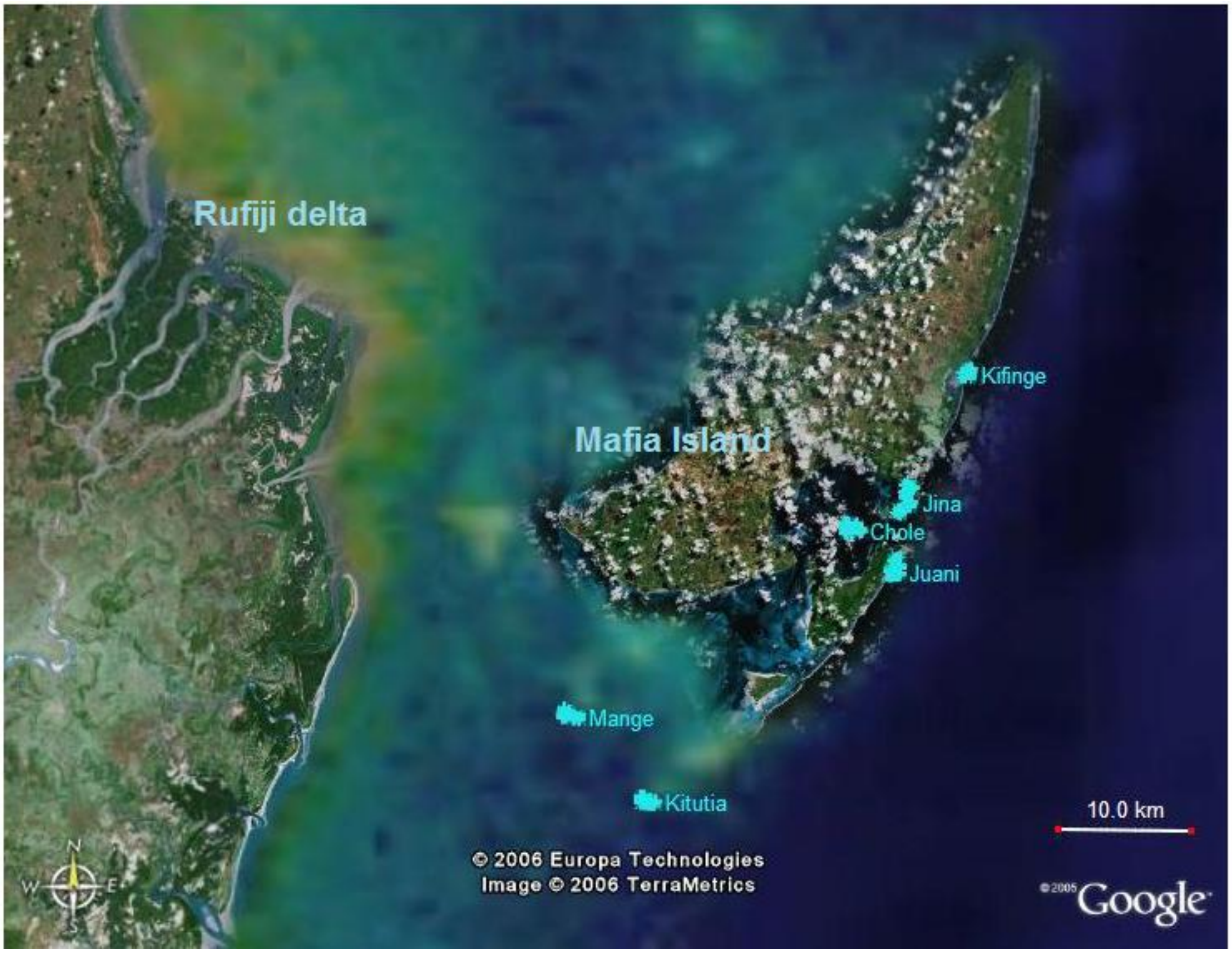

Figure 2: Location of Mafia Island (Source: Bryceson et al. 2006)

The climatic conditions of the area are influenced by two monsoon winds, the south and northeast monsoon. The southeast monsoon predominates from April to August with strong winds, while intermediate easterly winds blow from September to October. The northeast monsoon predominates from November to March, with relatively gentle winds. The sea surface temperature ranges from 25 ^{o}C to 31 ^{o}C with June to August being a relatively cool period. March to May is a period of long rains, with scattered showers in August and September and short rains usually from October to December (Fig. 3).

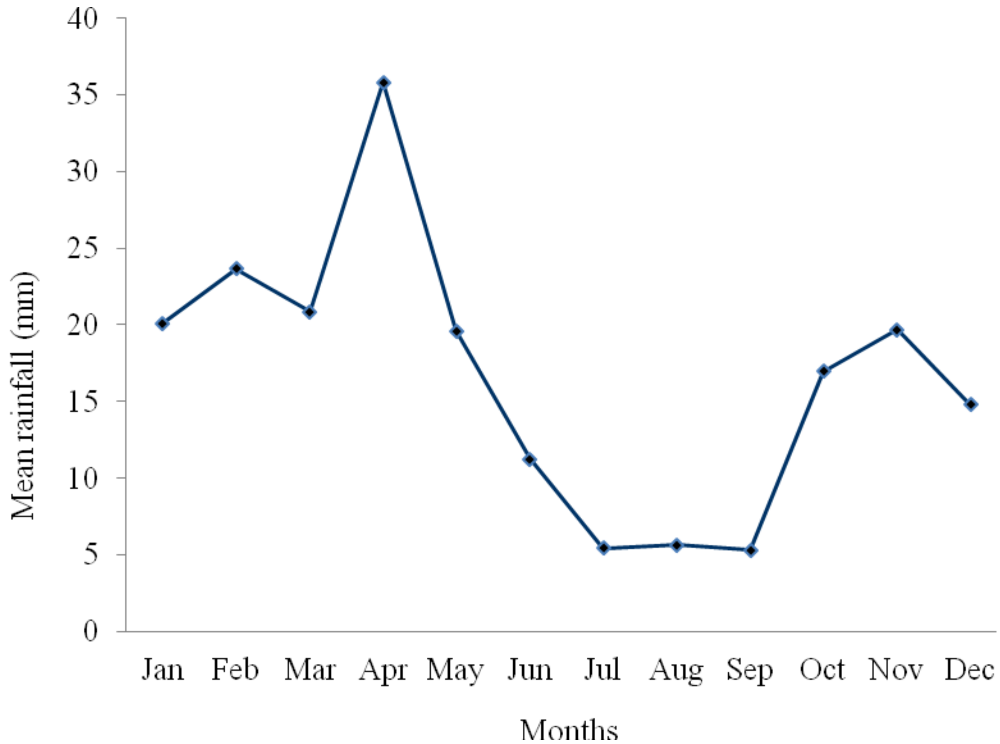

Figure 3: Mean monthly rainfall for the town of Kilindoni on Mafia Island between 2006 and 2010. (Data were taken from the metrological station in Kilindoni).

Fishing, farming, animal husbandry and petty businesses are among the economic activities providing a livelihood for communities in Mafia. Fishing is the most important economic activity for Mafia residents, since farming and animal husbandry are constrained by vermin (wild pig and monkeys), weak agricultural extension services, poor farming tools, and infertile soil (Bryceson et al. 2006). The development of infrastructure and the presence of the fish processing factory targeting the catch from small-scale fishers have made Mafia an attractive site for fish traders from Dar es Salaam, the closest major trading center. Approximately 75 % of marine fish at the Ferry integrated fish market in Dar es Salaam originate from Mafia Island coastal waters (Bryceson et al. 2006). The majority of the fishery produce is consumed locally and shellfish are exported. This practice is based on the 1997 fisheries policy strategy that "regulated importation and exportation of fish and products in order to safeguard the national food security" (URT 1997: 10).

This study was conducted in the southern part of Mafia Island which is under conservation measures through the Mafia Island Marine Park (MIMP) (Fig. 3). The area under conservation covers 822 km^2, of which 75 % is below the high water mark and more than 50 % is less than 20 m deep.

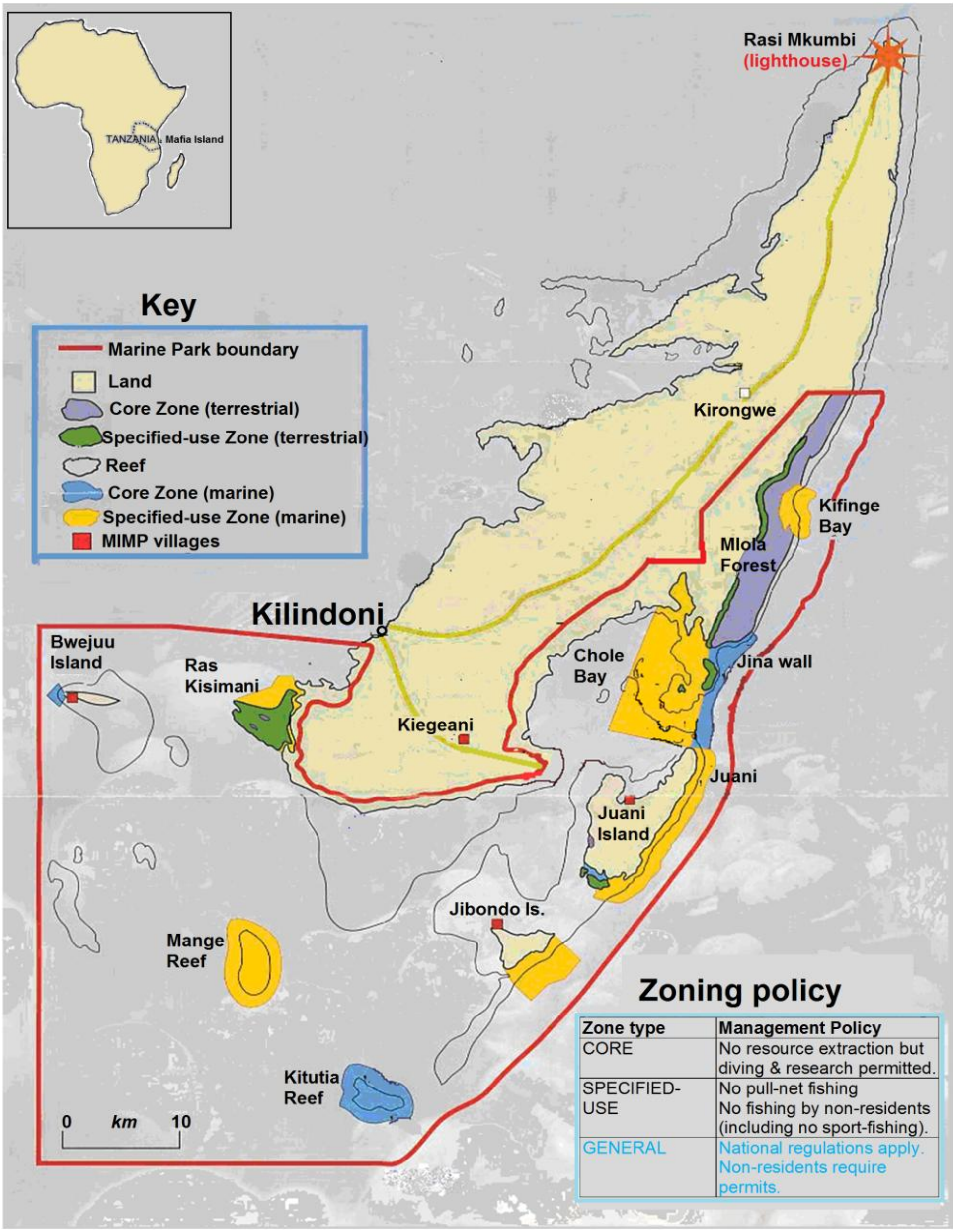

Figure 4: Location of study sites on a map of Mafia Island

Surveys of grouper populations were conducted at five sites inside the MIMP, namely the Kitutia, Jina, Juani, Mange and Kifinge reefs. The Kitutia reef is an isolated reef area which is considered to be the most important in terms of water flow, as it is at this point that the predominantly north flowing East African Coast current (EACC) divides to proceed along the Mafia channel and the outer reef. Different faces of the reef experience different environmental conditions. The Jina wall is situated between Mafia Island to the north and Juani Island to the south and forms part of the fringing reef system east of Mafia Island. The Jina and Juani reefs are easily accessed by fishers from Juani Island and Kiegeani. The Mange reef is a rocky reef dominated by a large sand bar at its northern tip. The southeast side of the Mange reef where the surveys were conducted is exposed to strong winds during the southeast monsoon. The Kifinge reef is located on the eastern side of the island and is visited mostly by fishers from Juani and Kiegeani. This reef is exposed to the north flowing east African oceanic current which is accompanied by strong onshore winds during the southeast monsoon. All of these sites are accessible during the northeast monsoon seasons. Detailed descriptions of these reefs are found in Gaudian & Richmond (1990).

The idea of establishing a marine park around Mafia Island began in the 1960s, based on a study by Ray in 1968, which recommended the protection of the coastal resources of Tanzania (Andrews 1998). Small marine habitats, including the Kitutia reef and Chole bay in Mafia, were declared as marine reserves in 1981; however, implementation failed due to a lack of finance and manpower for enforcement. During this time, all forms of destructive fishing, including dynamite, continued to be practiced in the area (Andrews 1998; Benjamisen & Bryceson 2012). Studies by Bryceson (1981), Kudoja (1985) and UNEP (1989) stimulated the need to establish a sound management plan for the sustainability of coastal resources. According to Ngoile (1989), the area proposed for protection against destructive fishing practices was the southern part of Mafia Island and its small islets. The area was chosen due to the pristine nature of the coral reefs, the diversity of marine organisms including fish, and the nature of the physical environment. After extensive study of the socio-economic, physical and biological status of the environment, a management plan was formulated for the area. The MIMP was established in 1994 and started operation in July 1995.

The Marine Park was created in order *inter alia* to conserve marine biodiversity and to promote sustainable utilization of marine resources and rehabilitation of damaged ecosystems (URT 1994; URT 2000; Francis et al. 2002). This initiative was a step towards realizing Agenda 21, chapter 17, part 85 of the Rio Conference (see earlier quotation).

Unlike in other countries such as South Africa (Prince Edward Islands) and Kenya (Watamu Marine Park), where MPAs are strictly no-take fishing, the MIMP is a multiple marine and land-use facility where human settlements have been allowed to continue within the park boundaries. Over 50 % of the population of Mafia lives within the MIMP boundaries. A zoning plan was adopted in order to integrate conflicting interests between user groups. The plan specifies varying levels of fishing restrictions, with zones designed as core zones (same as NTZs), specified-use zones (SUZs) and general-use zones, ranked in ascending order of potential fishing pressure. In core zones, no form of utilization is allowed, in SUZs specific forms of utilization are allowed, and general-use zones all legal forms of utilization are allowed. Details of the criteria used in selecting sites for zoning and the activities permitted in each zone are presented in the MIMP general management plan of 2000 (URT 2000; Francis et al. 2002).

3.2 Data collection and analysis

In this study, data were collected using a mixed methods inquiry approach, which combines quantitative and qualitative strategies (Creswell 2009:4) so that the overall strength of a study is greater than either quantitative or qualitative research might allow. According to Bryman (2008), both quantitative and qualitative research approaches have strengths and weaknesses, but the mixed methods approach offers the opportunity to draw from the strengths and minimize the weakness of both approaches in a single study (Johnson & Onwuegbuzie 2004).

Qualitative data on the ecology and biology of groupers were collected by interviewing fishers, and quantitative data was collected by experienced divers who conducted underwater visual surveys. Information on fisheries management approaches were obtained from various actors using qualitative approaches. Data collection methods included semi-structured interviews, focus group discussions, key informant interviews, informal conversations, direct observations and a literature review. Data was collected from August 2009 to March 2011.

3.2.1 Underwater visual census (UVC)

The objective of this part of the study was to elucidate the effects of the MPA on size, biomass and abundance of groupers (Paper I). Counts and size estimation of grouper species were determined using a standard underwater visual census (UVC) SCUBA diving technique for estimating the abundance of coral reef fishes (Fowler 1987; Samoilys & Carlos, 2000). The data was collected in March 2011 by experienced divers using the long-swim transects method. They used a GPS device connected to a depth-sounder to map the area surveyed and to track their movement and location. All sighted groupers were counted and identified to species level; unidentified species were photographed and identified later with the help of experts.

3.2.2 Specimen collection and measurement

Specimens of *Epinephelus malabaricus* were purchased randomly at sea from small-scale fishers throughout the year between September 2009 and December 2010 (Paper II). Fishers were residents of the villages of Jibondo, Juani, Kiegeani and Kilindoni. For each specimen, total length (cm), total wet-weight (kg), and gonadal wet weight (g) were measured in order to assess the size structure and estimate growth parameters. Gonads were examined macroscopically (see appendix 3) and histologically in order to evaluate maturity and to study the timing of the spawning season. Instrumentation and procedures used in histological and laboratory analysis (such as precision scales and balances) were according to recommended standards (see Paper II). The overall male to female sex ratio was calculated for the whole sample (n = 172). Information regarding the fishing gear used, fishing grounds and water depth were recorded at the time of sample collection. Length was used as a unit of size to assess the spatial distribution of *E. malabaricus* according to depth range and the choice of fishing gear.

3.2.3 Interviews

A total of 61 semi-structured interviews with resident fishers were conducted to generate data about fishing practices in the Mafia Island Marine Park (see Appendix 1). Fishers were identified in each ward in the villages of Juani and Kiegeani with the help of a ward leader. Among the identified fishers, three refused to be interviewed. Questions were designed to seek fishers' perceptions of the changes in the habitat, size and quantity of groupers as well as fisheries management practices (Papers I and IV). In addition, 16 interviews were conducted with experienced handline and basket trap fishers from Juani, Chole, Jibondo and Kiegeani to generate data on the species of groupers caught in the area, habitats, feeding habits, reproduction, and spawning aggregation (see Appendix 2) . These respondents were also asked about their selection of good fishing grounds, fishing seasons, and threats facing groupers in Mafia Island (Papers II and III).

Open-ended questions were chosen because they can provide details in fishers' own words, as well as a rich description of the respondent reality (Jackson & Trochim 2002). Answers given by fishers were coded manually by developing a coding scheme based on the frequency of the most common answers. A manual coding scheme was chosen because of the ability of a human reader to detect the subtleties and nuances of the answers given by fishers. Numerical summaries of the coded answers were generated by calculating the percentage of answers within each of the resulting coded categories. Descriptive statistics methods were used to analyse the quantitative data and results are presented either as percentages or counts. Multinomial logistic regression analysis and the Chi-square test were used to investigate any association between fishers' personal attributes and their perceptions of MPA outcomes (Papers I and IV).

Key informants interviews were conducted with old fishers (60-70 years of age) in Juani, the former chairperson of Juani village, the secretary of the village liaison committee in Juani, MIMP officials (warden, community development and enforcement officer), personnel in the fisheries unit in Kilindoni (fisheries officer and fisheries patrol officer), district officials (District Commissioner and District Executive Director), and managers at the fish processing factory (TANPESCA in Mafia and head office in Kipawa, Dar es Salaam). Interview questions were sent to the Tanzania Fisheries Division but no response was received.

A total of 12 focus group discussions were conducted in the villages of Juani (seven) and Kiegeani (five) to complement data obtained by other methods. Discussants were selected based on the criterion that they were representatives of the communities in question. The groups included the following types of participants: leaders of fishing groups; handline and basket trap fishers; migrant fishers from Zanzibar; village liaison committee members; and experienced fishers. The purpose of the focus group discussions was to establish the fishing calendar, map the local fishing grounds and rank communities in terms of wealth.

As the principal researcher, I spent thirteen months in the study area. During this time I worked closely with fishers and fish traders in the villages of Jibondo, Juani, Kiegeani and Kilindoni. Interacting closely with fishers and engaging in informal conversations provided me with the chance to learn and observe their fishing practices. This included fishing grounds, fishing seasons, types of fishing gear, fishing vessels and modes of propulsion used. The information recorded in the field notebook helped to supplement the data acquired through formal interviews and focus group discussions.

3.2.4 Desk studies

Desk studies enabled me to keep up to date with current debates on social and ecological linkages in natural resource management. The desk study involved reviewing peer-reviewed publications and reports on the MPA monitoring program and small-scale fisheries in tropical areas. An extensive literature review was conducted on the topics of ecology and biology of groupers, fishers' ecological knowledge, and management of marine parks. Secondary data obtained from MIMP reports were used for comparisons of ecological changes in groupers and to complement fishers' knowledge (Papers I and III). Literature searches enabled me to place empirical findings within a broader context and to gain insight into the contribution of this study to the topic of social and ecological linkages for sustainable coral reef fisheries.

3.3 Study limitations

This research involved collecting biological and ecological data about groupers in Mafia Island. The social component involved interviewing fishers to investigate the social context of their interactions with groupers. I choose to study groupers because they are a species vulnerable to overutilization and the results of this study may benefit conservation initiatives through the establishment of NTZs. Researching groupers in a marine park raised suspicion and fishers questioned the relevance of the research to local communities. The fear of fishing communities that the data they helped to generate might be used against them may have affected responses to interview questions. In order to overcome such obstacles, I minimized close interactions with the marine park management team to avoid any adverse influence on how local communities interacted with me during the fieldwork. A positive research outcome was that working closely with fishers about their traditional ecological knowledge bridged the gap between fishers and researchers. This approach created a common understanding, instead of considering fishers merely as the subject of study.

Fishing knowledge is not homogeneous among local communities due to stratification into age, fishing gear type, social classes and gender. It was difficult to balance numbers of participants from highly heterogeneous groups, as demanded by scientific research methods such as random selection. For example, in Mafia, those fishers considered by the community as 'rich' (a rich fisher is one who possesses a boat, an engine, is involved in fish trading and is able to lend money to other people according to community wealth rankings) were not willing to be interviewed for fear of jeopardizing their fishing activities. However, from field experiences, it became clear that rich fishers were involved in net fishing, whereas knowledge of the ecology and biology of groupers was more prominent among fishers using handlines, basket traps and shark nets. Therefore in order to best identify and balance participatory groups, it became necessary to understand the past social, political and economic experiences of local communities.

3.4 Ethical considerations

Permission to conduct research in Mafia was requested at regional, district and village levels. The objectives of the research were explained to all members of the communities where the study was conducted. During interviews, the objectives of the study were explained to respondents and informed consent was sought before their responses were recorded. Respondents were assured that they would remain anonymous and that the information gathered was to be used for academic purposes only. In order to protect informants and individual rights, confidentiality has been observed throughout this thesis. Other ethical obligations and protocols were recognized, such as the importance of local leadership, and respect for cultural practices and norms.

4 Results and Discussion

4.1 Responses of grouper species to marine reserves

Marine Protected Areas (MPAs) are seen as an efficient and inexpensive way of managing coastal marine fisheries against unregulated fishing activities (Alcala & Russ 1990; Bohnsack 1990; Roberts & Polunin 1993). One of the dominant narratives in the promotion of MPAs is their capability to protect large-bodied fish species, particularly those with a sedentary adult life in tropical coral reef areas. Most grouper species are solitary, meaning that they have limited movement and small home ranges (Sale 1978; Russ 1991), except during breeding aggregations when most species travel long distances to spawning sites. Various studies have reported benefits of MPAs in conserving grouper populations (Russ & Alcala 1996; Chiappone & Sealey 2000). However, few studies have compared before-and-after reserve establishment evidence of changes in abundance and biomass of grouper species (Claudet et al. 2006). Temporal and spatial trends in size, biomass and abundance of targeted species are simple stock size measures that are used to identify directions for fisheries management. Increased fishing pressure on targeted fish species tends to decrease standing biomass, fish abundance and average size, and cause the disappearance of spawning aggregations and changes in species diversity (Russ 1985). Reduction in the size of individuals diminishes the reproductive potential of the stock.

Scientific methods are used in the ecological assessment of fisheries resources (Samoilys & Carlos 2000), and as a measure of the state of a fishery (Degnbol 2002). It is believed that these ecological indicators are generally accepted by fishers and other stakeholders, yet fishers' knowledge is rarely considered (Christie 2005; Aguilar-Perera et al. 2009; Yasuè et al. 2010). Thus, I examined changes in size and abundance of groupers in the MIMP using fishers' perceptions, complemented by data from UVCs, in order to elucidate the value of fishers' perceptions to fisheries management.

The findings in this study indicate a gap between the perceptions of fishers from two villages and UVC data on changes in grouper size. These results are consistent with findings from other studies which indicate that fishers' knowledge and results from conventional science may not be in accord, due to many factors (Papers I, III and IV). The regression analysis showed that perceptions related to changes in size and abundance of groupers are significantly associated with fishers' area of residence. Fishers in one village perceived a decline in the size of groupers landed, while in another village they perceived either no change, or an increase. The difference in perceptions between the two villages could be attributed to differences in fishing capacity[6]. These results were not supported by evidence from the UVCs which does not show any substantial change in size structure of groupers.

Nonetheless, our analysis of fishers' perceptions and UVCs shows that biomass and abundance of groupers have declined since inception of the MIMP. These results are inconsistent with theoretical information on responses of grouper species to marine parks aiming at protecting fish stocks (Russ & Alcala 1996; Halpern 2003; Williamson et al. 2004; Claudet et al. 2010). In line with fishers' opinions in this study, the decline in biomass and abundance could possibly be explained as the effects of increased fishing pressure and the fact that large groupers prefer deeper areas (Paper I) due to higher temperatures in shallow areas (Wantiez et al. 1997; Pauly 2010; Galal et al. 2012).

This study also found evidence of spatial differences in the abundance of groupers recorded before-and-after the establishment of the park, in sites with different management regime. Sites designed as NTZs showed a higher abundance of groupers than specified-use zones (SUZs) (Papers I and IV), probably due to the differences in bottom topography of these two areas, and the effect of increased fishing pressure in fished zones (Paper IV). Analysis of UVC data showed a decline in abundance at all sites between 1995 and 2006 and a slight increase in NTZs between 2006 and 2011, probably as a result of improved conditions in coastal habitats (Paper IV).

Data on the size distribution of groupers after a period of 5 years to 2011 indicate no substantial differences in biomass between NTZs and SUZs. The population of groupers sighted during this study was dominated by small sized fish, which is consistent with fishers' knowledge on

[6] Fishing capacity is defined as the amount of fish (or fishing effort) that can be produced over a period of time (e.g. a year or a fishing season) by a vessel or a fleet, if fully utilized and for a given resource condition (FAO 2005-2015).

grouper species caught by various gear types (Papers II and III). The lack of spatial variation in the size of groupers between sites with different management regime implies that fishing pressure (Paper IV) may be playing a role in the spatial distribution of groupers (Sethi & Hilborn 2008; Lopez-Rivera & Sabat 2009; Claudet et al. 2010).

According to Samoilys and Carlos (2000) and Claudet et al. (2010), ecological traits are among the factors that influence responses of groupers to marine reserves. Other factors could be social behaviour, life history traits and natural occurrence (Claudet et al. 2010; Craig et al. 2011). Grouper species that are categorized as ‘cryptic’ (a behaviour serving to camouflage groupers in its natural environment) exhibited a significant negative response to protection, while the density of roving groupers did not show any substantial change. This pattern is explained as the effect of fishing since cryptic species are frequently caught by fishers (Paper III). Although the abundance of cryptic species showed a temporal decline, they were the most abundant grouper species sighted in both NTZs and SUZs when compared to large mobile and roving grouper species. Species such as *Plectropomus pessuliferus*, *Plectropomus punctatus*, *Plectropomus laevis*, *Dermatolepis striolata*, *Epinephelus polyhekadion*, *Epinephelus malabaricus* and *Epinephelus lanceolatus* were sighted rarely in NTZs. This observation implies that habitat preferences, natural occurrences and body size are traits that influence the distribution of groupers.

The findings from the current studies have important management implications from the perspective of MPAs and fish stock conservation. The assumption that NTZs contribute to increases in biomass and abundance of grouper species was not supported (Papers I and IV). Thus, a powerful additional management option may be to locate NTZs specifically to include sites such as deeper reef areas where large grouper species are likely to be found (Paper II). Evidence from this study indicates that both fishers’ perceptions and UVCs are influenced by a range of factors. These include psychological, economic and socio-cultural factors, the political situation which may affect fishers’ perceptions, and the intensity of sampling in UVCs that affects the power to detect temporal changes. Therefore, observations from the current studies underscore the role of eliciting information from a wide range of sources to support monitoring of the performance of MPAs (Papers I and IV).

4.2 Life history traits and characteristics of groupers

Life history traits of *E. malabaricus* (a grouper species frequently sighted at landing sites in Mafia and at the Ferry integrated market in Dar es Salaam) and linkages with fishers' knowledge and practices (fishing gear, depth of capture, spawning aggregation) were investigated. Traits analyzed include the histology of gonads, size structure, sex ratio and sexual maturity of *E. Malabaricus*. The gonadal analysis of specimens collected from fishers indicated that males are significantly larger than females; and no specimen in transition stage was found. Consistent with theoretical aspects on ecological and social linkages (Berkes & Folke 1998), this study found a significant association between size of fish caught and different types of fishing gear (Papers II and III). Large mature grouper species, e.g. *Epinephelus*, were less frequently caught by fishers using basket traps, handlines and nets, operating in shallow reef areas (Paper III). Corresponding to UVC results, fishers mentioned that they catch mostly sedentary, small-sized grouper species. We may conclude that there is a spatial overlap between fishing activities in Mafia and habitats that are suitable for small groupers.

Theoretically, it has been hypothesized that increased fishing pressure targeting mature fish is likely to selectively remove males, thereby adversely affecting the reproductive capacity of the population (Shapiro 1987; Mackie 2000). The results of this study show that large groupers (> 90 m) were caught in deep reef areas (40 to 400 m) during the northeast monsoon season, a period coinciding with calm seas (Gaspare & Bryceson 2013; Paper III). In particular, our evidence indicates that the lack of efficient fishing technology limits fishers in venturing far offshore (Paper III), thus permitting large groupers to resiliently absorb fishing pressure on the outer reefs. Thus, contemporary patterns of utilization by small-scale fishers serves conservation purposes, since a progressive shift towards fishing in deep reefs is hindered by limited technology. The observed fishing practices provide critical insights into the interactions between fishers and fisheries systems.

4.3 Complementarity of fishers' knowledge and conventional scientific knowledge

A lack of understanding about fishing patterns and the ecology and biology of targeted reef fish species has constrained the success of tropical marine fisheries management. At the global level, integration of fishers’ knowledge and conventional science is promoted in order to deal with challenges of fisheries management and other socio-economic problems (Brook & McLachlan, 2005). In this study, fishers’ knowledge was compared with conventional scientific knowledge of the ecology and biology of groupers. Further, catch data, as a simple indicator of stock abundance, was complemented with fishers’ opinions. The research emphasizes areas where the two knowledge domains complement or deviate from one another (Paper III).

Fishers’ knowledge on the seasonality of groupers coincides with fisheries-dependent data, with both sources indicating no seasonality in catching groupers. However, the lack of long-term catch data from all gear users limits our understanding of grouper utilization in the MIMP. Further, catch data indicate that large-bodied grouper species (e.g. *E. malabaricus, E. lanceolatus, E. fuscoguttatus* and *E. coiodes*) are caught by large hook-and-line and basket traps (see Appendix 5) operated in outer reefs (Gaspare & Bryceson, 2013). In addition, interviews with fishers revealed that shark-net fishing is also among the gear types used to catch groupers (Paper III).

Other areas where fishers’ knowledge coincides with conventional science reported in the literature include habitat preferences and feeding habits for groupers, and environmental threats facing groupers (Paper III). Although there is a close correspondence regarding grouper diet and habitat preferences, this study found disagreement between fishers’ knowledge and conventional science about spawning aggregations. Findings in this study show that the majority of fishers interviewed in Mafia claimed that groupers do not aggregate at all (Paper III). Scientific studies have found that spawning aggregations concentrate an abundance of fish at specific locations and times, and fishers target these aggregations, which in turn increases the vulnerability of groupers to overfishing (Robinson et al. 2014). Such disagreements call for further investigation, as they could lead to new insights or to improved dialogue between scientists and fishers.

This study found that fishers in Mafia lack knowledge regarding grouper spawning seasons and sex differentiation. This pattern was also observed by Begossi and Silvano (2008), contrary to studies conducted by Johannes et al. (2000) in the South Pacific, who found that fishers had detailed knowledge of fish reproduction. In addition to factors elaborated in Paper III, a lack of knowledge about the reproduction strategy of groupers may indicate that fewer adult fish in the reproductive stage are being caught by fishers. Gaspare and Bryceson (2013) found that immature *Epinephelus malabaricus* constituted about 55 % of all specimens analyzed. Likewise, findings in Paper I indicate that small sized groupers dominated in all surveyed sites.

However, it should be noted that there is a gap in scientific knowledge regarding the grouper spawning season; detailed collaborative studies with fishers would be desirable in order to investigate this phenomenon. Silvano and Begossi (2010) assert that verifying fishers' TEK through conventional scientific studies is a promising way to include TEK into management strategies effectively. The findings from this study will be useful in enhancing knowledge about the ecology and biology of groupers, thereby forming a base for integrating TEK and conventional science to enhance the effective management of small-scale reef fisheries.

4.4 Effectiveness of the MPA in terms of managing small-scale fisheries

Fishers' perceptions of MPA input and outcomes were investigated and factors affecting their perceptions were elucidated (Papers I and IV). Indicators used to evaluate effectiveness include ecological and social dimensions of the MIMP. Fishers' perceptions of the effects of the MIMP on fisheries in general and fishers' own fishing activities were used as proxy indicators for social acceptance of the MPA to local communities.

The findings indicate that the number of fishers has increased since inception of the MIMP. The increase is associated with the lack of opportunities for salaried employment and the influx of non-resident fishers. Fishing technology has not changed vastly in Mafia in modern times, since the majority of fishers still use small vessels with or without power, and no navigational equipment (Paper III). We found increased use of pull nets[7], decreased use of handlines and traps, and no evidence of dynamite or beach seine fishing. According to fishers, the choice of fishing gear type is closely linked to economic, technical and environmental factors, as well as management practices (Papers III and IV). Fishers are of the opinion that the decreasing trend in fish catch is a consequence of increased fishing pressure (Papers I and IV). Thus, the MIMP objective of promoting sustainable fishing is hindered by factors such as overlooking local fishing practices, socio-economic conditions of fishers, an unsustainable gear exchange program, and ineffectiveness of fisheries management outside MIMP boundaries (Paper IV).

There is a significant association between fishers' area of residence and their perceptions of the effects of the MPA on fisheries in general, and on fishers' own fishing activities. Fishers from the two communities felt that NTZs do not benefit fisheries as theoretically expected through an increase in abundance and biomass in fished zones (Papers I and IV). As is evident in Paper I, NTZs showed a substantially higher abundance of groupers than SUZs. A more detailed study to include other species of economic importance is an important area for future research to address the importance of NTZs in maintaining sustainable fisheries.

Fishers from Juani felt more impacted by the MIMP than fishers from Kiegeani. The difference in perceptions between the two communities is related to differences in fishing capacity and level of dependence on fishing for income generation (McClanahan et al. 2008). Fishers' participation in MPA planning and management is often used as a measure of social support in co-management arrangements (Bennett & Dearden 2014). However, fishers from the two communities in this study reported being dissatisfied with their involvement in the MIMP planning and management process. They also reported the existence of fisheries-related conflicts between fishers and MIMP about prohibition of certain types of fishing gear, access rights to fishing grounds, and the use of army forces during surveillance and enforcement activities. The degree of awareness and compliance with MIMP regulations shows a positive change. This evidence demonstrates that social acceptance by the two communities encompasses more than fishers' understanding of MPA regulations regarding prohibited gear

[7] Pull nets are seining net operated in shallow water, weighted nets are set in a circle and dragged into a boat.

types, compliance, and consequences of violation. In particular, issues such as access and user rights to fishing grounds, and restrictions on fishing gear demand proactive attention if we are to achieve sustainable small-scale fisheries.

4.5 Sustainability of reef fisheries

The findings regarding social and ecological linkages analyzed in this study can be expected to enhance the sustainability of coral reef fisheries. Areas identified as potential actions for contributing to the sustainability of reef fisheries are: using traditional ecological knowledge for the management of resources, improving existing management institutions and respecting social practices and cultural values.

The protection of vulnerable life history stages of grouper species remains crucial for long-term sustainability. Results from this study show that the majority of grouper species harvested were not yet mature, and large groupers that maintain reproductive potential of the population were landed infrequently. Currently there are no specific regulations controlling the harvesting of groupers. Sustainability is currently nurtured inadvertently by means of local circumstances, e.g. consumer preferences, limited fishing technology, and inaccessibility of offshore areas through natural temporal closures caused by monsoon winds. Additionally, cultural values such as women not eating groupers with dots on them, and large groupers being associated with the devil, also reduce the vulnerability of groupers to fishing. Findings from this study show that both scientists and fishers lack information about groupers in the offshore reef areas around Mafia Island. Nevertheless, it is known that large fish species prefer deeper areas with favorable oxygen levels (Pauly 2010).

The empirical evidence in this study does not prove that permanent area closure (NTZs), a practice commonly used in many modern systems of management, enhances the sustainability of small-scale reef fisheries. Fishers reported a decrease in abundance of groupers and fish catch trends, causing consequent livelihood deprivation for local communities. Fishers argued that fish abundance has decreased due to increased fishing pressure. This suggests that although MPAs may be necessary to meet conservation goals, they are not sufficient to promote the sustainability of fisheries. However, there is lack of long-term catch data to adequately monitor the performance of MPAs as a management tool. The above argument from fishers shows that the promotion of MPAs should be aligned with the economic development activities of local communities.

The diversification of knowledge sources could be an important method of reducing the risk of unsustainable fishing practices and subsequent failure of fisheries management. Fishers rely on traditional knowledge gained through long-term experiences and observations to make decisions regarding fishing and increasing daily yield. Their practices may be inconsistent with management regulations, but they are practically important in aiming to maximize their daily fish catch. Fishers' perceptions of the status of fish stocks provide an important opportunity to learn from fishers. This underscores the need to blend top-down management actions with traditional fishing practices of small-scale fishers in a local context. Local communities could gain new knowledge, and managers could use information generated by fishers to develop integrated management plans which would ensure the sustainable use of resources. Management interventions to promote the conservation of fisheries resources, that do not take into account fishers' preferences and threats to livelihoods could be unsuccessful, costly and increase conflicts between fishers and managers. Conversely, mutual knowledge transfer between fishers, scientists and managers has the potential to improve not only the effectiveness of MPA management of the resource, but also park-community relationships.

This study found that the majority of fishers were dissatisfied with the extent of their participation at the time of planning and inception of the MIMP. Many fishers praised the idea as good, but felt that there was lack of understanding about objectives and the implementation process. Impacts from fisheries closures and gear restrictions were not made clear to local communities at the time. As a result, conflicts continue to prevail in Mafia. This situation points to the need for transparent, collaborative management when implementing development projects. However, it should be remembered that personal characteristics, such as the age of a fisher, fishing gear type, and dependency on fishing for income all affect fishers' opinions and perceptions of MPA management outcomes.

The MIMP's viewpoint is that it is constrained in the promotion of sustainable fishing practices by improper planning, lack of effective fisheries enforcement outside MIMP boundaries, and over-dependency on fishing caused by persistent poverty in coastal communities (Paper IV). A particular example of pressure inside the park that is accelerating conflicts is the use of pull nets and surrounding nets[8] which are restricted in all zones of the marine park. In addition, national fisheries regulations allow the use of fishnets of mesh size above 1.5 inches, while the MIMP allows nets of mesh size above 2.5 inches. Seine netters use scoop nets of less than 1.5 inches to fetch fish, which is considered by the government as illegal.

Efforts need to be explored to reduce tradeoffs between local fishing practices and management actions or regulations that are contributing positively towards a sustainable system of combining fisheries management and conservation goals. Fishers suggested a round table forum where management issues can be discussed and agreed upon. The creation of a highly representative management forum, where local knowledge is given equal opportunity with conventional science in contributing to management decisions, is a promising tool for effective fisheries management and sustainability.

5 Conclusions and recommendations

This research study contributes to scientific evidence of the linkages between social and ecological aspects for sustainability in the context of small-scale reef fisheries around Mafia Island, Tanzania. It does so by combining the use of analytical tools from several interdisciplinary areas, namely fisheries management, biology and ecology. The study provides insights about interactions between and within social and ecological aspects of grouper fisheries. The theoretical framework used in this research provided some useful tools to investigate various aspects of reef fisheries systems, particularly grouper populations and behavior. These aspects include biological characteristics and ecological changes of the harvested species (groupers) with reference to management practices; the human dimensions of the fishery (fishers, fishing practices and technology); the knowledge elements (both fishers'

[8] Surrounding nets are seining net where a scoop net (*tandio*) is stretched under the net to draw in the catch.

knowledge and perceptions, and conventional scientific knowledge); and management institutions (MPA and national fisheries regulations). The combination of all these elements is a key approach in promoting sustainable linked social-ecological systems, according to Ostrom (2009).

Analysis of life history traits indicated that the size at first maturity of *E. malabaricus* landed in Mafia is ~79 cm, corresponding to 6 kg. Thus, the recommended weight for export (2 kg), which corresponds to an immature stage of growth (gonads not seen), should be reconsidered in order to sustain grouper fisheries. However, it should be noted that this study focused on only one species of groupers due to lack of specimens of other species (see Appendix 4) for quantitative analysis. Although different species of groupers have different growth rates, some large-bodied grouper species (e.g. *E. fuscoguttatus*) exhibit slow growth, similar to that of *E. malabaricus* (Pears et al. 2006).

This research has demonstrated that fishers' perceptions are an important factor to consider in monitoring the performance of MPAs. Although there was a gap between fishers' perceptions and UVCs on changes in size of groupers with reference to the inception of the MIMP, their perceptions of a decline in the abundance of groupers are consistent with UVC findings. It should be noted that perceptions differed significantly among fishers from the two communities which have different fishing capacity; furthermore, UVCs were affected by the intensity (number of replicates) and timing (only done during northern monsoon season) of sampling. In addition, behavioral responses of some species of groupers (e.g. roving and mobile groupers) to SCUBA divers can result in unreliable estimates through an underwater visual census (Willis & Babcock 2000). Thus, the use of video techniques for estimating abundance of large species is needed.

There was an overall low abundance and biomass of groupers in both NTZs and SUZs after the establishment of the park, but the NTZs exhibited greater abundance and species variation of groupers. The difference in the distribution of groupers between the two sites could be related to habitat quality and grouper habitat preferences. This study demonstrate that NTZs do not benefit fished zones through spill-over, indicating that NTZs are not necessarily the best option for managing reef fisheries. Further studies on mobility of both bottom-dwelling and pelagic species should be a priority, as this would have implications for which species will benefit from MPAs and the size of the area that should be protected. Tag and release, sonic tracking and natural marking techniques (such as through stable isotope analysis) will be useful in investigating such movement patterns.

Fishers' knowledge plays an important role in designing, implementing and assessing fisheries management plans, and should be regarded as complementary to conventional scientific knowledge. This research shows that fishers' knowledge may provide information about the dynamics of resource utilization (fishing gear and fishing grounds); species harvested and how they interact with each other; environmental factors affecting species development; and cultural practices that promote conservation in the eye of both resource users and managers. Fishers' knowledge and conventional knowledge can together serve as important sources of information for the co-management of small-scale fisheries at different spatial scales, although western trained researchers and managers may find this difficult to accept.

Regarding the effectiveness of the MPA, fishers' personal attributes significantly influenced their perceptions about MPA input and outcomes. A significant association was recorded between fishers' involvement in park planning and positive effects of the MPA. No significant association was found between involvement in enforcement of fisheries regulations and effects of the MPA on fisheries' own fishing activities. Conflicts between fishers and the MPA regarding fisheries management and regulations were reported. Fishers complained about a lack of alternative employment opportunities, limited access to productive fishing grounds, and gear restrictions. On the other hand, MPA managers complained that fishers are reluctant to provide fish catch data and village liaison committees tend to leak intelligence information about patrols. This points to the importance of community participation and the need to establish trust and respect between fishers and managers, in order to promote effective management of fisheries resources. In addition, fishery management measures outside protected areas are necessary to complement the protection offered by the MPA. We thus conclude that, in the eyes of fishers, the condition of coastal habitats has improved, but the benefit of the MPA to small-scale fisheries remains unclear.

In terms of the implementation of the ecosystem approach to fisheries (EAF) for sustainable small-scale fisheries at local level, this study recommends that conventional methods for assessment and monitoring of fisheries should integrate fishers' knowledge and perceptions. Joint assessment by fishers and scientists to develop an inventory of fish species harvested and to manage the dynamics of the resource at different temporal and spatial scales may help to minimize the cost involved in gathering information required to achieve effective fisheries management.

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Part B

PAPER I

Fisheries Management
and Ecology

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Temporal and spatial trends in size, biomass and abundance of groupers (Epinephelinae) in Mafia Island Marine Park: fishers' perceptions and underwater visual census surveys

L. GASPARE & I. BRYCESON

Department of International Environment and Development Studies (Noragric), Norwegian University of Life Sciences, As, Norway

Y. D. MGAYA

Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, Dar es Salaam, Tanzania

Abstract Fishers' perceptions of changes in grouper size and abundance were compared with scientific data collected via underwater visual censuses (UVCs) before (1995) and after (2006 and 2011) the establishment of the Mafia Island Marine Park. Perceptions on changes in the size structure of groupers differed among communities due to differences in fishing capacities. Fishers in one village had mixed perceptions, while in another village the majority (66%) perceived a decline in size, with small groupers dominating the catch. Similarly, UVCs indicated that size structure was dominated by small groupers at all times surveyed. Consistent with fishers' perceptions, UVC indicated that biomass and abundance of groupers declined in both no-take zones (NTZs) and specified-use zones (SUZs) between 1995 and 2006, with no substantial changes between 2006 and 2011. The NTZs had higher density and diversity of grouper species than SUZs, as would be expected from the differences in bottom topography in these two types of areas. The idea that NTZs could increase the biomass and abundance of groupers to benefit fished zones was not found, thus indicating that NTZs are not necessarily the best option for managing reef fisheries.

KEYWORDS: coral reef fish, ecological traits, fisheries management, fishers' knowledge, no-take zones, small-scale fisheries.

Introduction

Groupers are ecologically important as top-level predators in reef ecosystems, feeding on other fish, crustaceans and cephalopods (Unsworth *et al.* 2007). They play a major role in structuring coral reef ecosystems. Being highly priced fish, groupers are exploited heavily for commercial purposes and for consumption worldwide (Randall 1987). Globally, declines in abundance, size and catch-per-unit-effort of large groupers have been reported in different parts of the world, often due to lack of effective management strategies (Beets & Hixon 1994; de Mitcheson *et al.* 2013). For instance, in Kenya, landings of groupers declined to approximately 72% of previous levels due to increased fishing (Kaunda-Arara *et al.* 2003). Furthermore, most groupers are considered by the International Union for Conservation of Nature (IUCN) to be threatened or near threatened throughout their ecological range (www.iucnredlist.org). Life history characteristics of groupers, such as their behaviour in forming spawning aggregations, longevity, slow growth, low natural abundance, high trophic levels and patchy distribution, render them vulnerable to overfishing (Sadovy & Colin 1995; Roberts & Hawkins 1999).

A management approach used for many decades to combat overfishing with varying levels of protection, is the creation of large, multiple-use marine protected areas (MPAs) (Russ 2002; Hilborn *et al.* 2004; Roberts *et al.*

Correspondence: Lydia Gaspare, Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, PO Box 60091, Dar es Salaam, Tanzania (e-mail lgaspare@yahoo.co.uk)

2005). Several studies have documented findings that large-bodied fish species and those with a sedentary adult life, for example groupers, are more likely to benefit from the establishment of MPAs with no-take zones (NTZs) (Bohnsack 1998; Halpern 2003). Expected effects of NTZs are increased density, mean size and biomass of targeted fish species inside reserves, resulting in net exports of adult fish (the *spillover effect*) and eggs/larvae (the *recruitment effect*) to fished areas (Roberts & Polunin 1991; Chiappone & Sealey 2000; Roberts *et al.* 2003). The majority of studies of marine reserve effects on groupers have compared abundance/density and size/biomass changes in reserves and non-reserve areas (Zeller & Russ 1998; Unsworth *et al.* 2007). Few empirical studies have compared changes in abundance and biomass of species before and after the establishment of reserves in both NTZs and fished zones for better understanding of MPA performance and effect as a fishery management tool (Williamson *et al.* 2004; Claudet *et al.* 2006; Galal *et al.* 2012).

According to Misund *et al.* (2002) and Kolding (2006), the main target of MPAs by most environmental groups is small-scale tropical coastal fisheries, which are characterised by a lack of scientific data. Scientists tend to consider biological monitoring data as the only evidence required to document spatial and temporal trends in fish abundance, biomass and mean size of target species (Stem *et al.* 2005). However, in low income countries, such as Tanzania, such data may be very hard to obtain due to lack of funds. In such situations, fishers' perceptions of fish abundance offer important insights which may help to manage fisheries (Berkes *et al.* 2001; Christie 2005; Haggan *et al.* 2007; Aguilar-Perera *et al.* 2009; Yasué *et al.* 2010). Additionally, in collaborative fisheries management, fishers' positive perceptions of fish stocks in marine reserves may contribute to the sustainability of MPAs. Yasué *et al.* (2010) claimed that it is a mistake to consider that conventional scientific methods (e.g. UVCs) provide the only objective realities, compared to perceptions from resource users that have developed through observation and long-term experience. Both approaches are affected by various contextual variables, for example sampling methodology used in the collection of biological data, and social, economic and psychological factors that affect fishers' perceptions (Huntington 2000). Therefore, it is important to reconcile information from diverse approaches, which are complementary to one another, to understand how target fish species respond to the protection offered by marine reserves.

This study examined the responses of groupers to marine reserves in the multi-use Mafia Island Marine Park (MIMP), Tanzania, where groupers are targeted by both resident and migrant small-scale fishers. Because groupers often weigh more than other demersal species, they bring significant economic gains to fishers as they are sold on a per-kilogram basis. In 2002, the Tanzania Fisheries Division endorsed a trial fisheries policy allowing the export of grouper species weighing a minimum of 2 kg. The first processing factory that targeted groupers was built in Mafia Island. It is not known whether the factory exports groupers, because no legal permit has been issued (pers. comm. with Fisheries Division official). Due to potential higher levels of fishing driven by the pressure of export markets, it is anticipated that groupers will continue to be used in the specified zones of the study area.

This study examines changes in the size, biomass and density of grouper species over a 16-year period following the establishment of the MIMP to determine whether NTZs can be effective management strategies over a period of time. A further goal of this study was to assess how fishers' perceptions of changes in grouper size and abundance complement biological survey data gathered from UVCs. Research that documents perceived and observed changes in ecological traits of groupers is essential to understand how marine reserves affect targeted species of coral reef fish.

Methods

Study area and sites

Mafia Island and the small islets on its western and southern sides are located approximately 120 km south-east of Dar es Salaam and 21 km offshore from the eastern extent of the Rufiji Delta. The island is about 48 km long and 17 km wide at its widest point (Fig. 1). It covers an area of 413 km^2 and has a population of 46 438 (according to the 2012 census). The western side of the island is more sheltered from winds, but sedimentary materials discharged by the Rufiji River on the mainland influence water clarity. The eastern seaboard has a 33 km outer fringing reef and is exposed to the winds of the Indian Ocean. The continental shelf is narrow and falls to a depth of over 1000 m within 20 km of the main island. Several reefs and extensive intertidal flats occur along the southern and southwest parts of the island. The study was conducted in the southern part of the island which is under conservation measures as part of the MIMP.

The Marine Park was created in 1995, interalia, to conserve marine biodiversity and rehabilitate damaged ecosystems (URT, 1994, 2000; Francis *et al.* 2002). It is a multiple marine and land-use facility which continues to allow human settlement within the park boundaries.

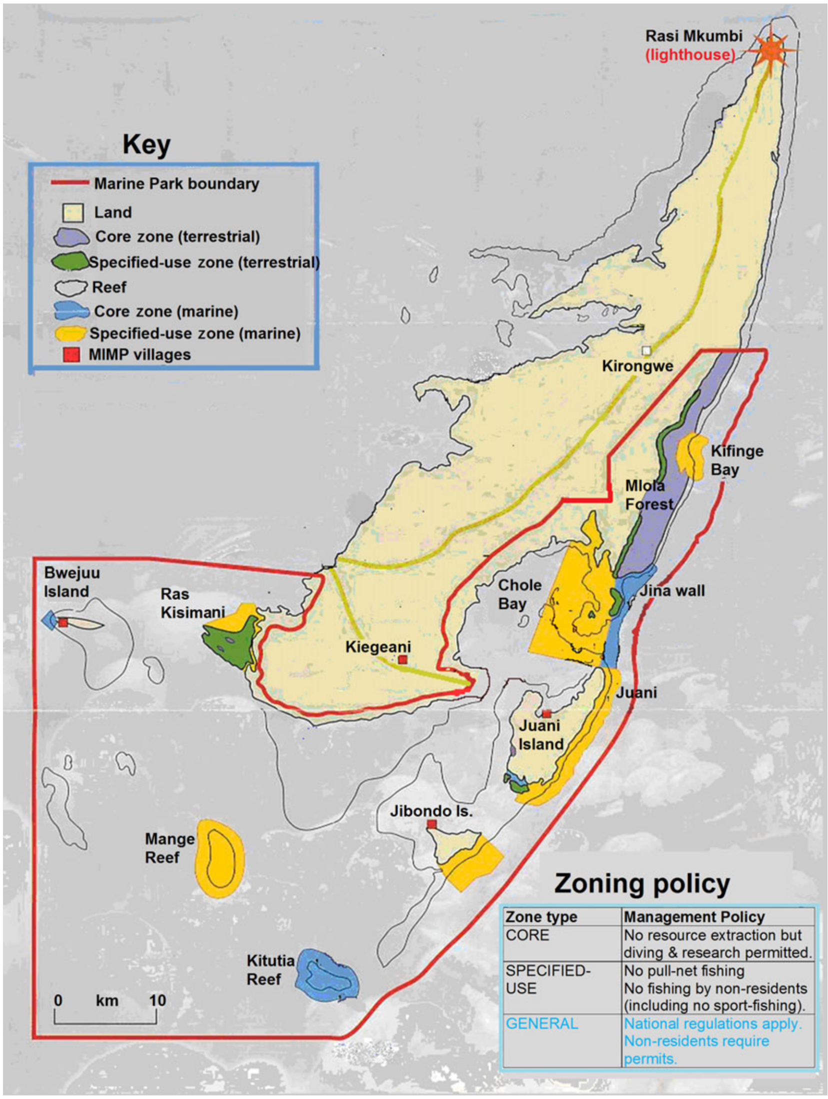

Figure 1. Map of Mafia Island, Tanzania, showing the diving sites and villages where interviews were conducted.

Over 50% of the population of Mafia lives within the boundaries of the MIMP. A zoning plan was adopted to integrate conflicting interests between user groups. The zones include no-take zones (NTZs), specified-use zones (SUZs) and general-use zones. In NTZs, no form of exploitation is allowed; in SUZs, specific forms of exploitation are allowed; and in general-use zones, all legal forms of exploitation are allowed. Details of the criteria used in selecting sites for zoning, and the activities permitted in each type of zone are presented in the MIMP general management plan of 2000 (Francis *et al.* 2002).

This study assessed grouper populations at five locations (fishing grounds) inside the MIMP, comprising two NTZs (Kitutia and Jina) and three SUZs (Juani, Mange and Kifinge reefs). The sites were selected based on their varying levels of management and human impacts, and after consultation with fishing communities and MIMP officials. All these sites are accessible by fishers from neighbouring villages only during the north-east monsoon seasons; therefore, no fieldwork was conducted during the time of rough seas (the southern monsoon season).

Data collection

Fishers' perceptions Group discussions, field observations, informal talks, key informant interviews and a review of secondary data were used to collect information concerning fishers' perceptions. Fishers were identified in each village with the help of ward leaders. The two villages (Kiegeani and Juani) were selected as they both have access to the same areas to fish but have very different fishing histories. Interviews were conducted as part of a wider study assessing the ecological sustainability of groupers in the waters off Mafia Island. Twenty-eight fishers from Juani and 33 from Kiegeani were selected for semi-structured interviews. Interviews were not restricted to certain types of fishers because groupers are caught by various types of fishing gear (pers. comm. with fishers). Personal information about fishers, for example area of residence, age, type of gear, years of fishing experience and use of motorised boats, was collected and used to perform statistical analyses. All interviews were conducted in Kiswahili by the author, and each interview lasted between 50 and 90 min. Fishers were interviewed at the landing site in the morning before going out to fish, or in the evening at their home after returning from fishing. All fishers were asked to rate whether grouper abundance and size had changed since the establishment of the park and to suggest reasons for any changes. The period before the establishment of the park was used as a milestone, because fishers could easily relate to such a specification of time compared with using numbers such as '16 years ago'. This became apparent during pre-testing of the questionnaire.

Underwater visual estimates of grouper size structure and abundance Quantitative estimates of grouper size structure and abundance were made in 2011 at five selected sites inside the MIMP area (Fig. 1) using a underwater visual census technique. The area surveyed by each diver was approximately 14 m wide and between 700 and 800 m long. Location and movement of divers were tracked using a GPS and echo-sounder instruments (YSI multiparameter instrument) operated from a moving boat to maintain consistency of transect. The distance was calculated from the GPS coordinates recorded at the start and end points of each of the respective dives. Intensely searched timed swims were conducted along a strip transect at a chosen bearing. Approximately 7 m on either side of the central line were surveyed to include any mobile, cryptic and wary groupers. All groupers sighted within a surveyed area were counted and identified to species level. Total fish length was estimated to within ± 5 cm (i.e. 5–10 cm, 10–15 cm, 15–20 cm, etc.). Juveniles of <10 cm were not counted because not only are they hard to identify, but also it was necessary to minimise potential errors associated with counting small individuals when surveying large areas (Bellwood & Alcala 1988).

A review of secondary data was also conducted, and results from Darwall *et al.* (1995) and Bryceson *et al.* (2006) surveys were included in this study for comparative purposes. The 1995 data were collected for 5 years (1989–1994) after a total of 352 dives had been completed (Darwall *et al.* 1995). These data were collected using the strip transect census (30- to 40-min dives) conducted by frontier volunteer researchers (Darwall *et al.* 1999). No data on size distribution were available for individual locations for the year 1995. The method used to collect data sets for 2006 was similar to 2011, and all were collected once a year without repeating transects due to budgetary constraints. Surveys were conducted by the same experienced divers in the same area as those in 1995. Data were collected during the north-east monsoon season because this is the most suitable time for accessing all sites.

Data analysis

Fishers' perceptions Fishers' responses concerning their perceptions on changes in size and quantity of groupers landed were presented as the proportions of fishers who perceived an increase, decrease, no change or do not know in each village. Descriptive statistics were used to analyse the trends in size and abundance of groupers fished now compared to before the establishment of the park. Content analysis was used on the perceived reasons provided by fishers for the changes. Lists of causes of change were summarised according to emerging themes and presented as direct quotes from fishers. Rating responses for size and quantity trend indicators were converted to nominal categories as follows: 1 = increase, 2 = decrease, 3 = no change and 4 = do not know. Nominal categories for fishers' personal attributes were assigned as follows: age: 1 = <30 years and 2 = more than 30 years; gear: 1 = static (handline, basket trap) and 2 = net (including shark net); fishing experience: 1 = <20 years and 2 = more than 21 years; use of engine: 1 = yes and 2 = no.

Categorical analysis using multinomial logistic regression (MLR) (statistical package IBM SPSS 20, Armonk, NY) at the 5% level of significance was used to test how fishers' personal attributes (area of residence, age, fishing gear, numbers of years spent fishing) are associated with fishers' perceptions. Age and fishing experience were included as an effect in the model to assess whether respondents with longer personal experience had differing perceptions of changes in the size and quantity of groupers. Similarly, their area of residence and type of fishing gear were included to assess the effect of fishing history and capacity on fishers' perceptions. As fishers perceived either an increase, decrease, no change or they did not know in terms of size and quantity trends, it was appropriate to use MLR for the purposes of understanding factors explaining the likelihood of perceived temporal changes in grouper populations.

Underwater visual estimates of grouper size structure and abundance The mean total length of a species was compared to the maximum size of that species recorded by Craig *et al.* (2011) and www.fishbase.org. The total biomass of groupers was estimated using the length–weight relationship calculated for New Caledonian lagoon Serranidae (Epinephelidae): $W = 0.0134L^{3.03}$, $n = 3403$ and $r = 0.996$ (Kulbicki *et al.* 2005). The formula developed by Kulbicki *et al.* (2005) was used because it combines 28 grouper species occurring in the Indo-Pacific region. Such relationships at higher taxonomic levels for reef fish species are limited in the western Indian Ocean. The biomass of groupers was expressed as total weight (kg) per area surveyed, and the density was expressed as the number of groupers per unit area (1000 m^{-2}) for each site; comparisons were made for the 1995, 2006 and 2011 sampling years. Temporal changes in density and biomass at each site are presented as percentages. Patterns in the distribution of grouper species were further analysed by multidimensional scaling (ALSCAL) using the computer package IBM SPSS 20. Dissimilarities in the grouper species distribution between the NTZs and SUZs were deduced based on the magnitude of the Euclidean distances in the two-dimension ordination matrix.

Results

Fishers' perceptions

The results from the multinomial regression model (Table 1) demonstrate that area of residence has a significant ($P < 0.05$) effect on responses to changes in grouper body size and abundances. Age, fishing gear and fishing experience do not show any significant association with fishers' perceptions of changes in grouper size and abundances. The majority (66%, $n = 32$) of respondents from Kiegeani were more likely to state that the size of groupers decreased since the MIMP has been in place (Fig. 2). Many respondents said that the decrease in size was due to increased fishing, shallow waters becoming warmer and large groupers having migrated to deeper areas. Others argued that catches of large groupers declined because the types of fishing gear used are not capable of catching large ones. Significantly, more fishers from Juani (39%, $n = 28$) than Kiegeani (6%, $n = 28$) believed that an increase in size occurred. An increase in grouper size was attributed to improvement in fishing gear (long handlines) to catch large groupers, and vessels that can venture into deeper areas on the outer reefs. Key informants pointed out that large groupers are caught by fishers coming from Zanzibar, who are capable of fishing in deeper areas. Other fishers perceived no change in grouper size because of morphological variations in grouper species and said that the size varies depending on the type and size of fishing gear used and the particular fishing ground.

On the question of whether they have caught more groupers since the establishment of the MIMP (Fig. 3), significant association between fishers' responses and their personal attributes was found (Table 1). Of the fishers that said the number of groupers decreased, 66% ($n = 32$) were from Kiegeani and 46% ($n = 28$) were from Juani. The two most common reasons mentioned for the decrease in grouper numbers were increased fishing and grouper preference for deeper reefs. 'Nowadays we are seeing much decrease, not only for groupers but all fish in general because of increased fishing and there are too many fishers now; even the world population has increased so we see everything is decreasing' (Interview # 6 Kiegeani 2011). Although the percentage of those who perceived an increase in quantity was low, they gave interesting reasons for this perception, for example improvement in fishing gear and new techniques for catching groupers compared to the past. Other reasons mentioned by a few (21%, $n = 61$) fishers in the two villages were the ability to fish offshore in deeper reefs and the presence of fishers from Zanzibar.

Underwater visual census

Temporal and spatial variation in grouper size, biomass and abundance No substantial temporal changes in size structure of groupers before and after the

Table 1. Factors influencing fishers' perceptions of changes in size and quantity of groupers based on multinomial regression analysis. Variables included are those with $P < 0.05$ after likelihood ratio test. $P < 0.05$ are shown in bold

Responses	Variables	*b*	SE *b*	*P*	exp(*b*)
Size*					
Decreased	Kiegeani	2.35	0.74	**0.001**	10.50
	Juani	−0.45	0.48	0.35	0.64
No change	Kiegeani	1.10	0.82	0.18	3.00
	Juani	−0.10	0.44	0.83	0.91
Do not know	Kiegeani	0.41	0.91	0.66	1.50
	Juani	−21.66	0.00	–	0.00
Quantity*					
Decreased	Kiegeani	1.10	0.44	**0.012**	3.00
	Juani	0.49	0.45	0.28	1.63
No change	Kiegeani	−20.50	0.00	–	0.00
	Juani	−0.13	0.52	0.80	0.88
Do not know	Kiegeani	−0.56	0.63	0.37	0.57
	Juani	−20.39	9445.45	1.00	0.00

* Reference category is 'increased'.

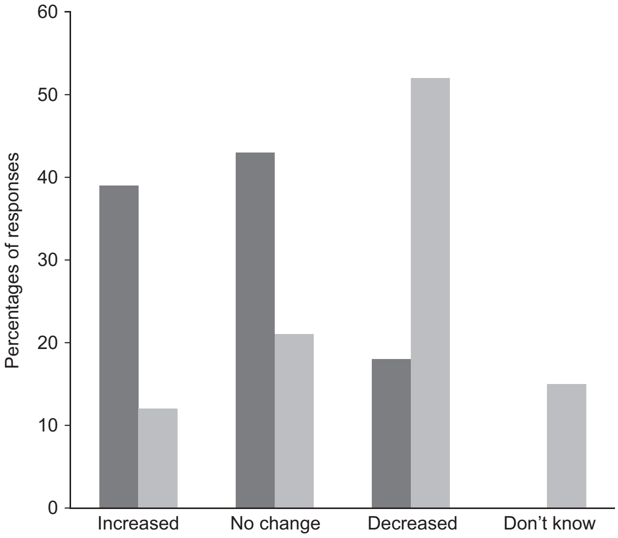

Figure 2. Fishers' perceptions of changes in the size of groupers: ▬, Juani; ▭, Kiegeani.

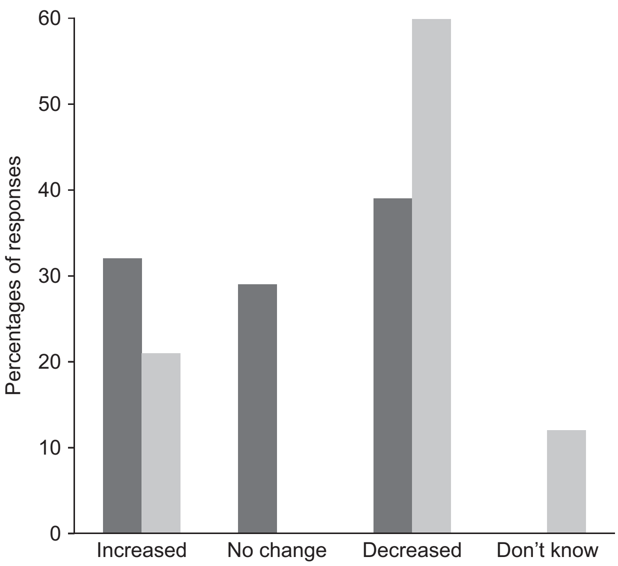

Figure 3. Fishers' perceptions of changes in the abundance of groupers: ▬, Juani; ▭, Kiegeani.

establishment of the park were found (Fig. 4). The populations of groupers in surveyed areas were dominated by small size classes at all three sampling times. Detailed grouper surveys in 2011 indicated that the average length for grouper species recorded in both NTZs and SUZs was low compared with their maximum length ever recorded (Fig. 5). Over the 5-year period from 2006 to 2011, grouper biomass within the Kitutia and Jina NTZs increased by a factor of 2 and 1.2, respectively. Within the SUZs at Juani and Mange, the biomass increased by a factor of 74 and 2, respectively, and declined by 79% at Kifinge (Fig. 6). Nevertheless, there appears to be a temporal decline in abundance of groupers for all size classes, except for the intermediate size (50 cm). A decline in abundance was found for species such as *Cephalopholis argus* (Schneider), *Cephalopholis miniata* (Forsskål), *Epinephelus* sp. and other unidentified species (Fig. 7). The density of roving species, *Plectropomus laevis* (Lacepède) and *Variola louti* (Forsskål), did not show any substantial change. Furthermore, there was a substantial temporal decline in grouper abundance within the NTZs and SUZs (Fig. 8) over the period of 11 years since protection. In the Kifinge and Mange SUZs, it declined by 90 and 95%, respectively, between 1995 and 2006. From 2006, the density increased by a factor of 3 and 9 in the Kitutia and Jina NTZs, respectively.

Spatial variation in species level abundance During the 2011 census, 14 species of groupers were sighted (Table 2) for both NTZs and SUZs according to behaviour groups. Ten species occur within the NTZs, four species occur within the Kifinge and Mange SUZs, and eight species occur in the Juani SUZ. Cryptic species were the most abundant species recorded in both NTZs and SUZs, with *C. miniata* having the highest density recorded in the Jina NTZ (1.41 fish 1000 m^{-2}) and lowest in the Juani SUZ (0.48 fish 1000 m^{-2}). *Variola louti* was the second most abundant species, with a density of 0.77 fish 1000 m^{-2} recorded in the Kitutia NTZ and lowest density of 0.34 fish 1000 m^{-2} in the Kifinge SUZ. Dissimilarities in grouper species distribution represented by Euclidean distances separating the samples in the two-dimensional matrix for all sites were greater for *C. miniata and V. louti* on dimension 1 compared with other species (Fig. 9) which appears to correlate with NTZs (Table 2). The abundance of *Aethaloperca rogaa* (Forsskål), *Plectropomus pessuliferus* (Fowler) and *Epinephelus coeruleopunctatus* (Bloch) was higher in SUZs. Species such as *Epinephelus lanceolatus* (Bloch), *Plectropomus laevis* and *Plectropomus punctatus* (Quoy & Gaimard) *Epinephelus malabaricus* (Bloch & Schneider) and *P. punctatus* exhibited substantially low densities in both NTZs and SUZs.

Discussion

Using fishers' perceptions and UVC data collected before and after the inception of the marine park, temporal and spatial trends in size, biomass and abundance of groupers in the waters of Mafia Island marine Park were assessed. Consistent with proponents of the use of fishers' knowledge in resource management (Haggan *et al.* 2007; Rochet *et al.* 2008), understanding fishers'

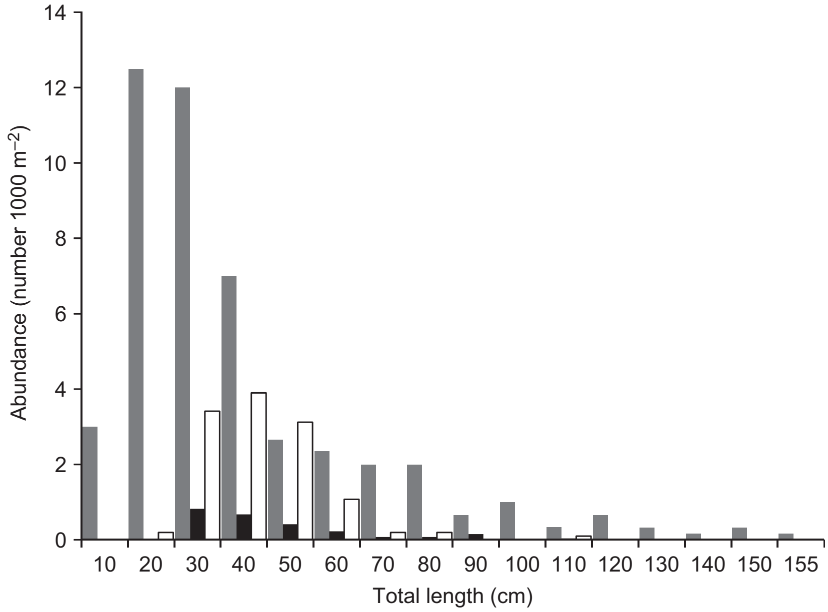

Figure 4. Size composition of groupers in the Mafia Island Marine Park at three sampling times (data for 1995 and 2006 were extracted from Darwall *et al.* (1995) and Bryceson *et al.* (2006), respectively) ▬, 1995; ▬, 2006; ▭, 2011.

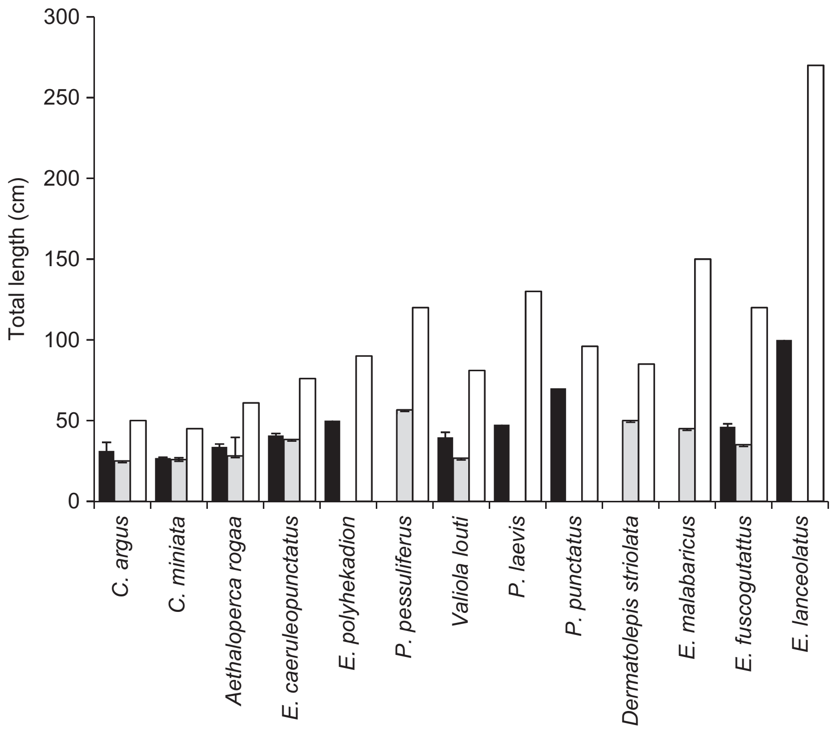

Figure 5. Lengths obtained from underwater visual censuses for grouper species during the 2011 surveys in NTZs and SUZs. Standard deviations of means pooled across two (Kitutia and Jina) and three (Juani, Kifinge and Mange) surveyed sites are shown. (Lmax = maximum length according to Craig *et al.* (2012); www.fishbase.org ▬, NTZs; ▭, SUZs; ▭, Lmax).

perceptions of changes in resource abundance is important since their information complements scientific study in managing fisheries (Haggan & Neis 2007). The key findings of this study are: (1) fishers' perceptions of changes in size of groupers were mixed and inconsistent with results obtained by UVCs; (2) NTZs exhibit higher

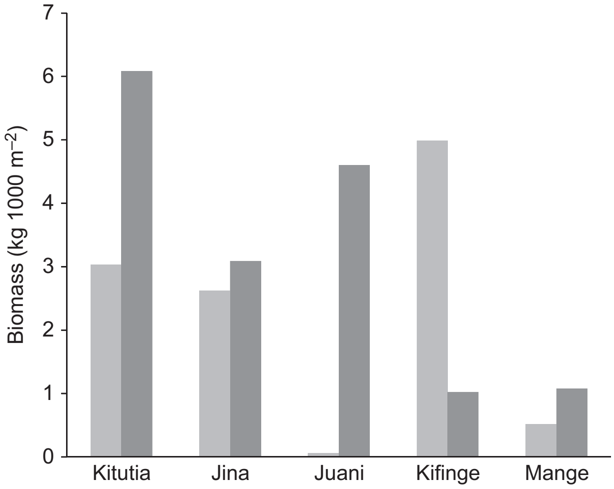

Figure 6. Biomass (kg 1000 m^{-2}) of groupers at five sites at two sampling times (Kitutia and Jina are NTZs; Juani, Kifinge and Mange are SUZs). ▭, 2006; ▬, 2011.

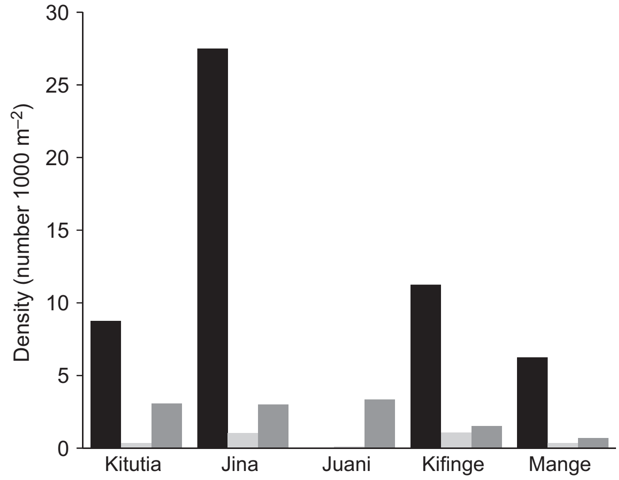

Figure 8. Density of groupers at five sites at three sampling times (Kitutia and Jina are NTZs; Juani, Kifinge and Mange are SUZs). ▬, 1995; ▭, 2006; ▬, 2011.

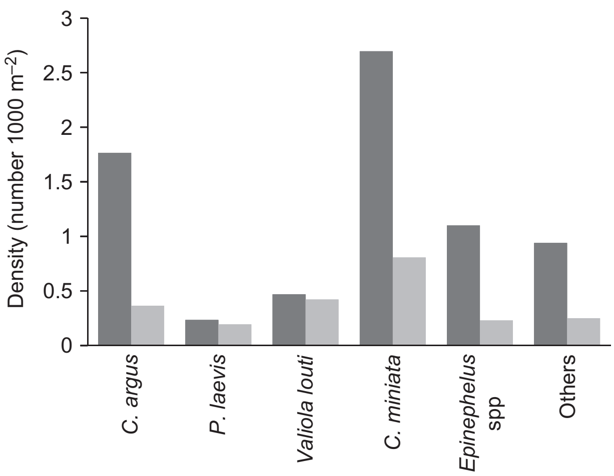

Figure 7. Density of grouper species at two sampling times, species combined into the 'Others' category include *Epinephelus tukula* (Morgans), unidentified black groupers and dwarf groupers (<30 cm). ▬, 1995; ▭, 2011

biomass and greater abundance of groupers than SUZs, with the exception of the Juani SUZ; and (3) differing perspectives between fishers' perceptions and UVCs illustrate the importance of multiple information sources to understand the state of fisheries resources.

Temporal changes in size, biomass and abundance from fishers' interviews and UVCs

Results indicate a gap between perceptions of fishers from the two communities and UVC data on changes in grouper size. Similar results were demonstrated in a previous study (Daw *et al.* 2011), which also suggests that fishers' perceptions and UVC data may not be in accord due to many factors affecting the two data sources (Daw *et al.* 2011). In this study, the differences in perceptions between communities may be partly attributed to having different fishing histories and capacities. UVCs on the other hand are affected by the intensity of sampling that influences the ability to detect temporal changes. Variability in divers, sample size, sampling time and sampling location between the 1995, 2006 and 2011 surveys could have impacted the results. Greater sample size per sampling period and more frequent sampling would have enhanced the statistical power to detect change (Samoilys & Carlos 2000). However, based on Huntington's (2000) suggestion, reconciling information from all possible available sources supported the cross-checking of the data collected in this study.

While fishers from the two communities had mixed perceptions on changes in the size of groupers, UVC data do not demonstrate any substantial change in size structure before and after the establishment of the MIMP. Large groupers (length of more than 100 cm) were rarely sighted in surveys conducted in the years before (1995) and after the establishment of the park (2006 and 2011). Consistent with UVC data, Kiegeani fishers reported that the size structure of groupers presently caught is dominated by small fish. This congruence reflects the spatial overlap between habitats for small groupers as indicated by UVC data, and fishing grounds currently accessed by fishers (Gaspare & Bryceson 2013; L. Gaspare, I. Bryceson & K. Kulindwa 2015). UVCs target shallow reefs, which is where Kiegeani fishers tend to fish, while Juani fishers occasionally can expand onto offshore reefs. In addition, Juani fishers

Table 2. Number of species and density (number 1000 m^{-2}) of groupers recorded in 2011 at the five sites under two management schemes in the Mafia Island Marine Park (Kitutia and Jina are NTZs; Juani, Kifinge and Mange are SUZs)

	Kitutia	Jina	Juani	Kifinge	Mange	All sites	Global population trend (Craig *et al.* 2011)
Cryptic species							
Cephalopholis argus	0.58	0.27	0.32	–	0.29	0.37 ± 0.14	Stable
Cephalopholis miniata	0.67	1.41	0.48	0.67	–	0.81 ± 0.41	Decreasing
Aethaloperca rogaa	0.10	0.33	0.64	0.17	–	0.31 ± 0.24	Unknown
Epinephelus coeruleopunctatus	0.19	0.16	0.48	-	–	0.28 ± 0.18	Unknown
Epinephelus polyhekadion (Bleeker)	0.10	–	–	–	–	0.10 ± 0	Decreasing
Roving species							
Plectropomus pessuliferus	–	–	0.48	–	–	0.48 ± 0	Decreasing
Variola louti	0.77	0.43	0.48	0.34	0.10	0.42 ± 0.24	Stable
Plectropomus laevis	0.19	–	–	–	0.20	0.20 ± 0. 01	Decreasing
Plectropomus punctatus	–	0.05	–	–	0.10	0.08 ± 0.04	Unknown
Large mobile species							
Dermatolepis striolata (Playfair)	–	–	0.16	–	–	0.16 ± 0	Unknown
Epinephelus malabaricus	–	–	–	0.34	–	0.34 ± 0	Decreasing
Epinephelus fuscoguttatus (Forsskål)	0.38	0.33	0.32	–	–	0.34 ± 0.03	Unknown
Epinephelus lanceolatus	0.10	–	–	–	–	0.10 ± 0	Decreasing
All species (Mean ± SE)	0.34 ± 0.89	0.43 ± 0.17	0.42 ± 0.05	0.30 ± 0.11	0.17 ± 0.05		

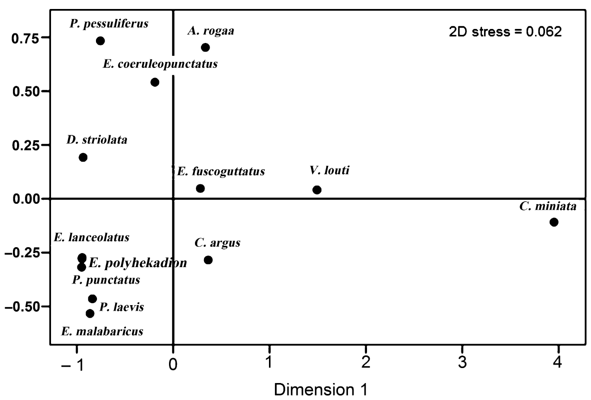

Figure 9. Two-dimensional scaling configurations showing the distribution of grouper species recorded in NTZs (Kitutia and Jina) and SUZs (Juani, Kifinge and Mange) during March 2011.

interact with fishers from other areas who have caught groupers further than 15 km away from Juani (personal observation). The responses of some Juani fishers could be related to the availability of efficient fishing gear through the MIMP gear exchange programme, which enables them to fish further afield during the northern monsoon season. Hence, their fishing activities are spread over a wider area, including much deeper reefs, as opposed to those targeted for UVCs. Moreover, the availability of outboard engines may have encouraged these fishers to target large groupers. The natural habitat for large groupers is deeper reefs which are traditionally not fished due to their inaccessibility – it is only the availability of more efficient gear that can shift fishing activities to much deeper areas. These findings are in agreement with Bender *et al.* (2013) who asserted that fishing capacity, fishing gear and fishing grounds affect resource users' perceptions.

In accordance with data from fishers' perceptions, the assessment of UVCs shows that the abundance of groupers declined between 1995 and 2006, but displays a slow recovery after a period of 5 years to 2011. The decline is reflected in fishers' statements that groupers have moved to deeper areas, which signals declining abundance in fished areas (Chiappone *et al.* 2000). Consistent with fishers' perceptions, UVC data show a low biomass and abundance of groupers in both NTZs and SUZs after the establishment of the park. The idea of NTZs increasing the biomass and abundance of groupers to benefit small-scale fisheries in fished zones was not demonstrated in this study.

The results contrast with similar studies conducted elsewhere that show an increase in biomass and abundance of groupers after the inception of a marine park (Russ & Alcala 1996; Halpern 2003; Williamson *et al.* 2004). According to Alcala (1988), increased fishing pressure results in changes in size distribution, biomass and abundance of groupers. The decline in abundance observed in this study could possibly be explained as the effect of increased fishing pressure. Similar findings are reported by Galal *et al.* (2012), namely that the number of groupers declined inside NTZs in Nabq Sinai, Egypt, between 2000 and 2011, and the decrease was attributed to fishing in the NTZs. No potential effects of poaching in NTZs were explored in this study, thus the influence of such activities remains unclear. Another factor could be that large groupers prefer deeper areas as a result of higher temperatures in shallow areas (Pauly 2010). The observed congruence between perceived changes in the abundance of groupers and UVC data is encouraging for situations in which resources are not available to initiate a fisheries-independent monitoring programme for effective management of MPAs.

Temporal and spatial variation in species level abundance from UVCs

Results here indicate that the density of cryptic and large mobile species declined in abundance, while the density of roving groupers remained unchanged. This pattern could be explained by factors related to habitat and food preferences, social behaviour, life history traits and natural occurrences (Claudet *et al.* 2010). *Cephalopholis* spp are small species that are less mobile and are more abundant naturally (Craig *et al.* 2011). The decline in *C. argus* and *C. miniata* could be related to differential effects of fishing, because these species inhabit shallow areas rich in corals and often form social groups during spawning (Shpigel & Fishelson 1991). Although Craig *et al.* (2011) indicated a global stable trend for *C. argus*, in Mafia, they are constantly caught by small-scale fishers using nets and basket traps (personal observation). Roving grouper species, although more visible, and active predators are naturally less abundant and are caught infrequently by small-scale fishers. *Valiola louti* is a widespread grouper species, while *Plectropomus laevis* is naturally rare, achieving a density of <1 fish 1000 m^{-2} (Craig *et al.* 2011) comparable to the density recorded in this study (0.2 fish 1000 m^{-2}). The large body size and late maturity of *Epinephelus* species make them vulnerable to decline (Jennings *et al.* 1999; de Mitcheson *et al.* 2013).

The spatial analysis of groupers shows that the NTZs had slightly more grouper species than the SUZs, with the exception of the Juani SUZ that had eight species, perhaps due to its location near to the Jina NTZ. Species such as *C. argus*, *C. miniata*, *V. louti*, *E. fuscoguttatus* and *Aethaloperca rogaa* all benefitted from the NTZ management strategy. This could be related to habitat quality and preferences for groupers (Garpe & Öhman 2003). Of the thirteen species that were recorded in this study, three species, *E. malabaricus*, *Dermatolepis striolata* and *Plectropomus pessuliferus,* were not found in NTZs and it is not clear why. However, according to Craig *et al.* (2011), these species are large, mobile and naturally rare, achieving a density of <1 fish 1000 m^{-2}.

Conclusion

Determining how targeted reef fish species respond to a marine reserve using a mixed methods approach is a complex challenge. This study illustrates the importance of combining fishers' perceptions and UVC data to evaluate the status of groupers in a protected area. This is the first study to use body size structure and density data collected before and after the inception of the Mafia Island Marine Park in Tanzania. While UVCs provide a more objective fish count, these data are limited to shallow areas in sites suitable for diving, short time frames in observing the changes, and small sample sizes for data collected in the years 2006 and 2011. Fishers are a good source of information in detecting long-term trends because they are active in the field, they make observations about fish and their environment all year round, and have built up many years of experience (Johannes & Neis 2007). Nevertheless, the perceptions of fishers may be affected by social factors such as their fishing histories and the use of motorised boats.

The results obtained from interviewing fishers and analysing UVC data indicate that the density of groupers has declined over the last 16 years, with fishing activities moving further and deeper into the ocean. Possible causes of the decline in biomass and abundance of groupers include increased fishing, changes in water temperatures and life history traits. Furthermore, the idea of NTZs increasing the biomass and abundance of groupers to benefit fished zones was not demonstrated in this study, thus indicating that NTZs are not necessarily the best option for managing reef fisheries. Many of the larger grouper species, such as *E. malabaricus*, *E. lanceolatus* and *Plectropomus punctatu*s, are not protected by NTZs. Thus, a powerful additional management option may be the establishment of NTZs located specifically in sites such as deeper reef areas where large grouper species are likely to be found.

The results of this study should encourage fishers and fisheries managers to work together towards effective fisheries management and marine conservation. The results form a baseline for further monitoring of the performance of MPAs in protecting fish stocks. Future studies in the Mafia Island Marine Park may include other fish families of ecological and economic importance at local, national and international levels.

Acknowledgments

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Erratum

The word ‘Dimension 2’ on y-axis of Fig. 9 (on page 345) was erroneously deleted

The name de Mitcheson (on page 348) should read Sadovy de Mitcheson

PAPER II

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Research Article

Reproductive Biology and Fishery-Related Characteristics of the Malabar Grouper (*Epinephelus malabaricus*) Caught in the Coastal Waters of Mafia Island, Tanzania

Lydia Gaspare[1,2] and Ian Bryceson[1]

[1] *Department of International Environment and Development Studies (Noragric), Norwegian University of Life Sciences, 1432 Ås, Norway*
[2] *Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, P.O. Box 60091, Dar es Salaam, Tanzania*

Correspondence should be addressed to Lydia Gaspare; lgaspare@yahoo.co.uk

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The reproductive biology and fishery-related characteristics of the Malabar grouper (*Epinephelus malabaricus*) (Bloch and Schneider, 1801) specimens were investigated. The size of females ranged from 25 to 113 cm total length (L_T), with 50% sexually mature at 79 cm L_T, and the males (97 cm to 114 cm L_T) were larger than the females. Due to the sex ratios and size distribution of the sample, it appeared that the groupers change sex between 97 and 113 cm L_T. However, the gonadal histology data lacked specimens in the transitional stage. The spawning peak occurred in November, as defined by the presence of ripe females, and the spawning season lasted from September to February. The size of the fish correlated positively with the water depth at capture, which is also related to oxygen levels in deep water being more favourable for larger fish. Larger specimens (>100 cm L_T) were targeted by fishers between December and February, when the northeast monsoon coincides with calmer weather and the spawning season. Fishers were interviewed, and observations were made on fishing gear, vessels, and grounds. There was no indication that small-scale fishers targeted spawning aggregations; therefore, fisheries independent research is recommended in order to verify the time, location, and behaviour of the spawning of Malabar groupers for management and conservation purposes.

1. Introduction

The population size structure, mode of reproduction, maturity, and fisheries characteristics (fishing gear, vessels, and fishing grounds) of various Epinephelinae are well documented in the Western Atlantic, the Caribbean, Southeast Asia, and Australian waters [1–4]. In contrast, virtually no such data is available for the same species in Tanzanian waters, despite their frequent presence in local fish markets (pers. observations). Being highly priced fish, the Epinephelinae are heavily exploited in many tropical areas of the world for commercial purposes, aquaculture ventures (e.g., *Epinephelus malabaricus* and *Epinephelus coioides*) and for recreational and local consumption [4–6]. The increasing exploitation is attributed to growing markets, especially worldwide export markets for the fish [7, 8].

Groupers have long lifespans, are slow growing, relatively large in size, and have a low natural mortality rate. The larger species form breeding aggregations, and most species are protogynous hermaphrodites. Among the Epinephelinae, monandry protogynous hermaphroditism is the most common sexual pattern [9]. A few species, such as the *Epinephelus coioides* and the *Epinephelus andersoni*, are diandry, where the males can either develop from the females or they can develop directly from the juvenile phase [10–12]. The latter sexual pattern suggests that some females do not change sex at all, and some males do not pass through female stages at all.

We therefore argue that protogynous sex change, slow growth rates, late maturity, low numbers, growing to a large size, and the forming of breeding aggregations render the fish susceptible to overfishing [8, 13–15]. Where the *Epinephelus* *malabaricus* have been studied, for example, in Prony Bay, New Caledonia [16], and in north-western Australia [17], they have been found to be protogynous hermaphrodites [5, 18] and form spawning aggregations [16]. The species is listed on the International Union for Conservation of Nature (IUCN) Red List as a near-threatened species [16]. Understanding the size structure, reproductive pattern, maturity, and spawning seasons of the *Epinephelus malabaricus* is important for proper fisheries management. For instance, the increase in fishing pressure targeting mature protogynous hermaphrodite fish is likely to selectively remove males from the population. This could result in imbalances in sex ratios (i.e., the population becomes female biased) which may reduce sperm availability. The subsequent reduction in sperm production could adversely affect spawning activities due to the diminished probability of egg fertilization [3, 9], and hence the resilience of the species. Likewise, a fishery that targets immature specimens that are smaller than sexually mature ones could compromise its sustainability, since this will reduce the number of specimens that enter the adult population and are able to breed. Garcia et al. [19] propose the adoption of balanced harvesting of fish of all size ranges, which would avoid the consequences to the ecosystem that come as a result of size-selective fishing.

Despite management efforts (such as gear management, temporary and permanent closed areas, and limitation of the number of fishers or vessels) that exist on the coast of East Africa [20], the near-shore fish resources on some parts of the East African coast have been exploited to various degrees by fishers using traditional fishing vessels and gear-like traps, hook-and-line, spearguns, and nets [21]. A similar situation has been reported in the Indo-Pacific and Caribbean regions, and some species of groupers have practically disappeared from commercial catches [22].

In 2002, the Fisheries Division of Tanzania endorsed a trial fisheries policy allowing the export of groupers of a minimum of 2 kg in weight [23]. The stated policy goal was to improve the livelihoods of coastal communities and increase fish product exports. However, no information on the reproductive pattern, size structure, and maturity of the groupers was available to ensure the sustainability of the fisheries. Understanding the population characteristics of the *Epinephelus malabaricus* is necessary in order to develop appropriate management and conservation measures. Therefore, this study aims to determine the reproductive biology and fishery-related characteristics of *Epinephelus malabaricus* caught by small-scale fishers in the inshore waters of Mafia Island, Tanzania. More specifically, the objectives of this study are to determine (1) sexual maturation based on the histology of the gonads, (2) the size structure and sex ratio, (3) the relationship between size and fishing gear used, and the depth at which fish were caught, (4) the size at first maturity, and (5) to document the spawning season. By analysing the reproductive pattern, size structure and maturity of *Epinephelus malabaricus*, we are generating information that is fundamental for predicting responses to fishing, conservation, and management initiatives in the waters of Mafia Island, Tanzania.

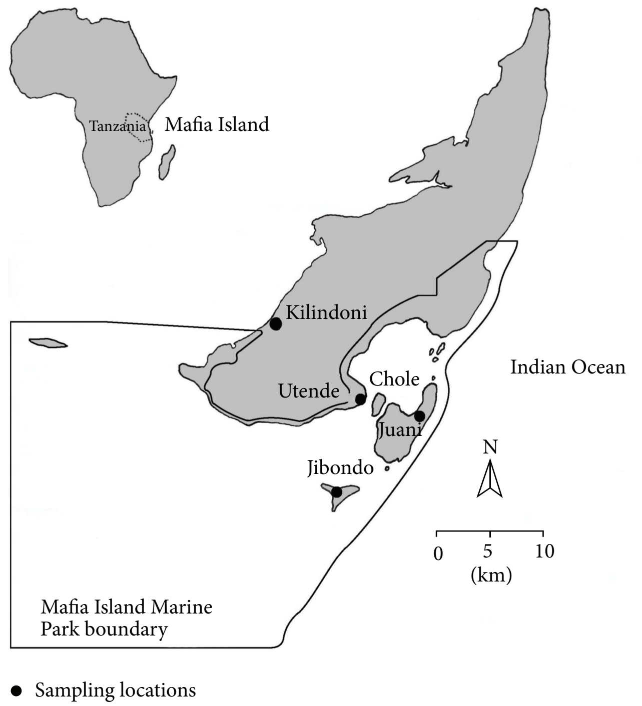

Figure 1: Map of Mafia Island, Tanzania, showing study area.

2. Material and Methods

2.1. Study Site and Sample Collection. Mafia Island and its small islets, located on its western and southern parts, lie approximately 120 km southeast of Dar es Salaam and 21 km offshore from the eastern extent of the Rufiji Delta. The island is approximately 48 km long and 17 km wide at its widest point and has an area of 413 km^2. Several reefs and extensive intertidal flats are found along the southern and southwest part of the island. According to the latest census conducted in 2012 the population of Mafia Island is 46,438.

This study was conducted in the southern part of the island, which is part of a conservation area managed by the Mafia Island Marine Park (MIMP). The park is a multiple marine and land-use facility allowing human settlement within the park boundaries. In order to integrate conflicting interests between user groups, a zoning plan was adopted. The zones are divided into a core zone, where no form of environmental exploitation is allowed, a specified-use zone, where specific forms of environmental exploitation are allowed, and a regulated-use zone, where all legal forms of environmental exploitation are allowed (Figure 1).

The area under conservation covers 822 km^2, of which 75% of the surface area is below the high water mark and more than 50% of the area is less than 20 m deep. The climate of the area is influenced by the biannual monsoon winds and the northward flowing East African Equatorial Current [24, 25]. The area is characterised by dry and rainy seasons, and it is warm and humid throughout the year. The southeast monsoon (*kusi*) predominates from June to September with strong winds, while intermediate easterly winds (*matilai*) blow in October. The northeast monsoon (*kaskazi*) predominates from November to March with relatively gentle winds, and is followed by a rainy season (*masika*) from late March to the end of May. Scattered showers (*mchoo*) fall in August and September, while short rains (*vuli*) fall between October and December. The surface temperature of the sea ranges from 25°C to 31°C, with June to August being a cool and dry season [26].

Specimens of *Epinephelus malabaricus* were purchased throughout the year from small-scale fishers operating at sea during the period between September 2009 and December 2010. The fishers resided in the villages of Jibondo, Juani, Utende, and Kilindoni. Information regarding the gear used to catch the fish, the fishing grounds, and the water depth were recorded at the time of sample collection. Furthermore, fishers were interviewed in order to solicit information regarding their knowledge of the spawning aggregation of the groupers.

2.2. Size Structure. The size structure of the *Epinephelus malabaricus* was assessed based on length and weight [27]. The total length (L_T) of the specimens was taken using a measuring board and recorded to the nearest 1 cm. The total wet weight (W_T) was measured using a weighing scale and recorded to the nearest 1 kg. The gonads were removed, blotted dry, and weighed (M_G) to the nearest 0.01 g using an electronic weighing scale. They were examined macroscopically and then preserved in Bouin's solution for approximately 48 hours. They were then transferred into a solution of 70% ethanol and stored for histological examination in order to evaluate maturity.

2.3. Histological Analysis and Classification. The gonads were subsampled by taking tissue sections from three parts of the gonads: close to the junction of the two gonad lobes (proximal), from the middle (medial), and from the end of the gonad (distal). The tissue samples were dehydrated through a series of increasing concentrations of ethanol, cleared in xylene, infiltrated, and embedded in paraffin wax. Transverse sections of 7 μm, made using a hand rotary microtome, were mounted on glass slides using Mayer's egg albumin. The samples were then rehydrated, stained with Harris hematoxylin, and counter stained with eosin. Both ovaries and testes were examined using a light microscope. The ovaries were classified based on the presence of the most advanced and numerous types of oocytes present. The assignment to sexual categories and maturity development was based on criteria shown in Table 1.

2.4. Data Analysis. The length frequency distributions were used to describe the size structure of the fish, using the computer packages MS-Excel 2007 and OriginPro 7. Their maturity was identified by examining the gonads, and gonadal development was staged in order to identify seasonal maturational cycles. The size at sexual transition was estimated by examining the size range in which males overlapped with females. The median value and its confidence limits were taken to represent the size at which sex change occurs [34].

The timing of the spawning season was studied using the appearance of the gonads according to the predefined stages of maturation over time. Length-weight relationships were obtained using the log linear regression model $\log_{10} W_T = \log_{10} a + b \log_{10} L_T$, where W_T is the weight in grams, L_T is the total length in centimeters, log a is the intercept of the regression model, and b is the regression coefficient. The size at sexual maturity (L_{50}) of females was estimated by fitting a logistic regression function, available from OriginPro 7, to the proportion of mature fish in 5 cm L_T size categories. The overall male to female sex ratio was calculated for the whole sample size at 5 cm class intervals. A two-sample independent t-test was used to determine the differences in size between females and males. For all statistical tests that were conducted, the level of significance was set to $P < 0.05$.

3. Results

3.1. Histological Characteristics. The histological analysis of a total of 172 specimens of *Epinephelus malabaricus* showed no difference in maturation development between proximal, medial, and distal gonad sections. The gonads of *Epinephelus malabaricus* that were less than 92 cm in total length consisted only of ovarian tissues, and all juvenile specimens showed female gonads with previtellogenic oocytes. No male specimens were found in small sized classes. Moreover, no individual fish was found to be in a transitional stage, that is, possessing degenerative ovarian tissues, proliferating testicular tissues, or being mature resting females, spent females, or newly transformed males. The cellular development used to assign sexual maturity to different stages of both male and female fish is illustrated in Figures 2(a)–2(f) for females and Figures 3(a)–3(i) for males.

3.2. Size Structure and Sex Ratios. The statistical model for the length-weight relationship provided a good fit ($r^2 = 0.98$, Figure 4). *Epinephelus malabaricus* had isometric growth, that is, $b = 3.08$. Caught *Epinephelus malabaricus* specimens ranged from 25 cm to 114 cm L_T and from 0.26 kg to 27 kg in total weight. Females ranged from 25 cm to 113 cm L_T (mean 66.6 cm ± 15.4 SD; $N = 136$) and from 0.3 kg to 23 kg in total weight (mean 5.3 kg ± 3.7 SD). Males ranged from 97 cm to 114 cm L_T (mean 102.8 cm ± 4.7 SD; $N = 36$) and from 12 kg to 27 kg M_W (mean 17 kg ± 3 SD). Males were significantly larger than females (2-sample t-test, $\alpha = 0.05$, df = 163.596, $P < 0.0001$). Up to 94 cm L_T, there were only females, and beyond 94 cm L_T the sex ratio was one female for every four males (Figure 5). Overall, of the 172 specimens collected over a period of sixteen months, 55.3% were immature females, 23.8% were mature females, and 20.8% were males. Excluding the immature females, the adult sex ratio was 1 : 1.3 and 1 : 3 mature females to males during January and February, respectively. Mature female specimens were completely absent in the samples during March, April, and August. From May to July, and in November, the samples contained only mature females. In September and October, the ratio of mature females to mature males was 1.3 : 1 and 3.5 : 1, respectively, and the corresponding ratio in December was 1 : 1.8.

3.3. Relationships between Fish Size, Gear, and Depth of Capture. The majority (77.4%) of the specimens of *Epinephelus*

Table 1: Description of histological characteristics of various maturity stages of female (F) and male (M) gonads of *Epinephelus malabaricus* [1, 28–32]. Terminologies for oocyte stages are based on Wallace and Selman [33].

Stage	Development	Histological descriptions
F1	Immature	Chromatin nucleolar stage dominant (large nucleus surrounded by a thin layer of cytoplasm; the nucleus contains a single and large nucleolus). Lamellae highly organised and well packed with previtellogenic oocytes, no signs of prior spawning in the form of brown bodies, postovulatory follicles or atretic oocytes. Thin gonadal wall and no spermatogenic materials present.
F2	Late immature	Perinucleolar oocytes present
F3	Early ripening	Chromatin nucleolar, perinucleolar, and cortical alveolar (appearance of York vesicles in the cytoplasm) oocytes present, with migrating nucleus
F4	Late ripening	Cortical alveolar and yolk granule oocytes abundant
F5	Ripe	Yolk plate formation is complete; oocytes are amoeboid in shape, and yolk granule oocytes (vitellogenic stages) are dominant.
F6	Mature running ripe	Oocytes in all stages of development may be present, although those in the early and late maturation stages are dominant. Hydrated oocytes or postovulatory follicles are present indicating that spawning had started.
F7	Mature resting	Lamellae not compact and often vacuolated, filled with previtellogenic oocytes; presence of brown bodies or atretic vitellogenic oocytes and intralamellae muscle bundles as the evidence of prior spawning and thick gonadal wall.
F8	Spent	Over 50% of the large yolk granule oocytes are atretic, brown bodies and postovulatory follicles are generally present. Lamellae disrupted and disorganised, with empty spaces previously occupied by oocytes.
	Transitional	Female tissue is degenerating; male tissue proliferating. Dorsal sperm sinus not fully formed; gonads consist of ovarian tissues but sperm crypts are present.
M1	Maturing	Post-transitional, newly transformed testes. Lobules containing spermatogenic cysts in all developmental stages. No sperm within the sperm sinuses; seminiferous lobules may be evident with previtellogenic oocytes in varying amounts that may fill the gonads.
M2	Mature ripening	Lobules containing cysts of male sperm cells in all developmental stages (spermatocytes and spermatids). Spermatozoa (tailed sperm) are free in the lumen. Little or no sperm in the sperm sinuses.
M3	Resting	Little spermatogenic activity, some free residual of spermatozoa within lobule, lumen, and sperm sinuses. Abundant cysts of spermatogonia inside the lobules. Vascularised and well developed stromal tissues.
M4	Mature ripe	Large pools of spermatids and spermatozoa in the large lumen of lobules and in the spermatic sinuses (dorsal and central).
M5	Spent	Testes disorganised and vacularised, with numerous brown bodies and well developed stroma tissues.

malabaricus were captured by hook-and-line, 17.3% were captured by basket traps, and 5.3% were captured by seine nets. The length composition of the *Epinephelus malabaricus* varied markedly according to the method of capture (Figure 6). There is no world standard for measuring hook size. The measurements used here are based on the fishers' own descriptions of the hooks they use. The hooks were categorized by a number, with 1 being the largest hook and 12 being the smallest hook. Small hooks (numbers 6 to 12) and lines with a breaking strain (diameter) of 0.8 mm to 1 mm, caught fish of 30 cm to 109 cm L_T, while the larger hooks (numbers 1 to 5) and lines with a diameter of 1.3 mm to 1.9 mm, caught specimens of 60 cm to 114 cm L_T. Likewise, small basket traps (BT), measuring approximately 0.5 × 0.4 × 0.15 m with a mesh size of 3 cm, caught small to medium sized fish of between 24 cm and 79 cm L_T, while bigger basket traps, measuring approximately 1.06 × 0.61 × 0.30 m with a mesh size of 8 cm, caught only larger fish of more than 100 cm L_T. Seine nets with stretched mesh of 6.35 cm caught fish of less than 89 cm L_T.

The size of the *Epinephelus malabaricus* that were caught correlated positively (Pearson correlation = 0.552, $P < 0.001$, $N = 106$) with the depth of capture. The majority (68%) of *Epinephelus malabaricus* with sizes between 24 cm and 99 cm L_T were caught in shallow reefs of less than 20 m depth, while 32% of fish with sizes between 55 cm and 114 cm L_T were caught in deep reef areas at a depth range of 40 m to 400 m (Figure 7).

Field observations and interviews with fishers revealed that large *Epinephelus malabaricus* of more than 100 cm L_T were caught mainly using large hook-and-line, big basket traps, and wooden-planked boats (*mashua*) equipped with outboard engines. Fishers using passive gear (small and medium sized basket traps or hook-and-line) and traditional vessels (dugout and outrigger canoes) were able to catch smaller sized specimens of *Epinephelus malabaricus* found in shallow waters. The fishers stated that it is dangerous for them to use small vessels with large hook-and-line that catch large groupers because, once the fish is hooked, it can pull strongly and overturn the vessel. Also, strong water currents make it

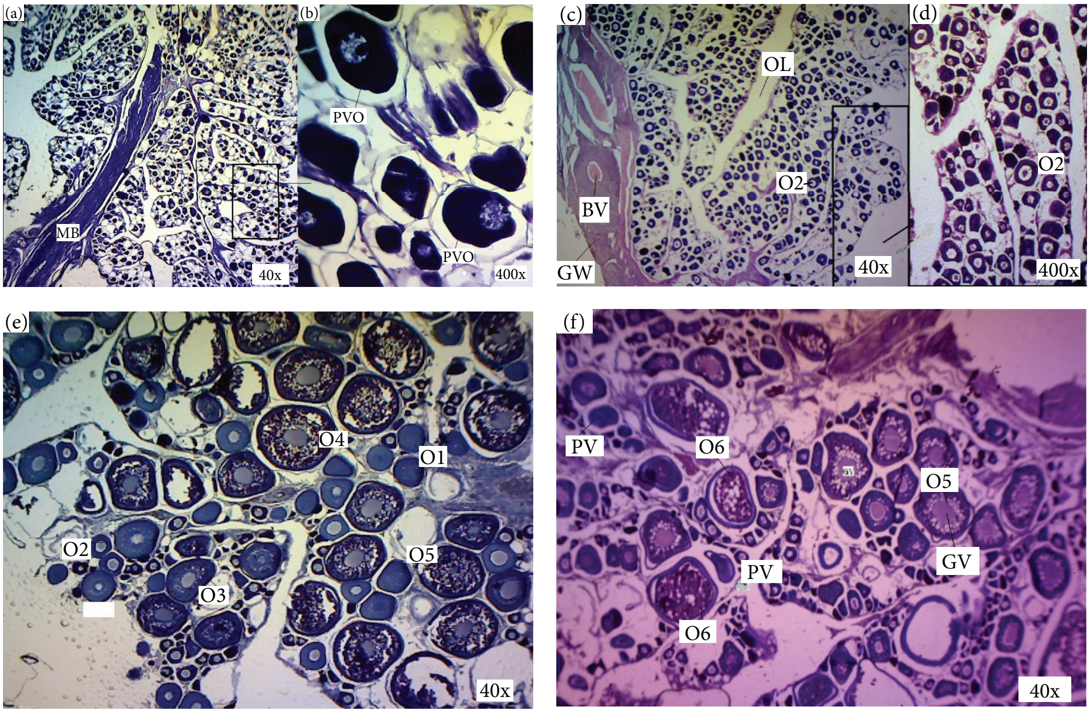

Figure 2: Histological section of ovarian stages of *Epinephelus malabaricus* (a) Immature (F1) collected 25 January 2010, 66 cm L_T, 5 kg W_T, 4.4 g G_W (c) Mature ripening (F3) collected 28 February 2010, 79 cm L_T, 9 kg W_T, 20 g G_W; (e) Late ripening (F4) collected 30 January 2010, 82 cm L_T, 9.5 kg W_T, 124 g G_W; (f) Ripe (F5) collected 19 October 2010, 96.5 cm L_T, 16 kg W_T, 185 g G_W. PV: previtellogenic oocytes; OL: ovarian lumen; MB: muscle bundle, BV: blood vessel; GV: granule vesicle; GW: gonadal wall, O1–O6: oocytes stage F1–F6.

difficult to fish with a handline due to the line being pulled by the water. Furthermore, small vessels are unable to withstand strong winds, and hence handline fishing is minimal during the season when the seas are rough. The period from April to August is a rainy season, which is followed by strong southern monsoon winds that hinder access to deep reefs where the large *Epinephelus malabaricus* are found.

3.4. Sexual Maturation. The length at 50% sexual maturity (L_{50}) of female *Epinephelus malabaricus* was ~79 cm (7.5 kg), based on the examination of 41 mature (F3–F6) and 102 immature (F1 and F2) female specimens (Figure 8). The minimum length at the onset of sexual maturity of the females that were analysed was estimated at 55 cm L_T, and the size at 100% sexual maturity was 113 cm L_T (Figure 8). No significant differences in size were observed between F3, F4, F5, and F6, and mature ripening (M2) males were significantly larger than immature and ripening (F1–F4) females. Of the mature specimens collected from September to February, 31.7% and 69.4% were female and males in a ripening condition, respectively (Table 2).

3.5. Spawning Season of Epinephelus malabaricus. Based on a histological assessment of gonads, ripe females were recorded in September ($N = 2$), October ($N = 1$), November ($N = 3$) and December ($N = 3$), and ripe males ($N = 6$) in September, October, December, and February. No sample of either sexes in ripe condition was collected between March and August (Figures 9(a) and 9(b)). Some fishers asserted that groupers do not aggregate to spawn; others said they did not know because they do not dive and therefore do not observe the fish underwater.

4. Discussion

4.1. Size Structure and Sex Ratios. We differentiated between females and males using histological analysis. The results show that the *Epinephelus malabaricus* from around Mafia Island displays isometric growth (i.e., $b = 3.08$) similar to estimates reported by Kulbicki et al. [35]. Length frequency distribution analyses for *Epinephelus malabaricus* showed that male specimens were completely absent in the small size classes. The proportion of females declined as the size classes became larger, and very few females were present in the maximum size class. This is typical for haremic protogynous species where males attain a larger size in order to defend their territories or spawning sites that females visit [36, 37]. Furthermore, the linear decrease in the proportion of females above the mean size at sexual maturity indicates that a sex change occurs as females become larger.

No differences in the size structure were noted when comparing the specimens used in this study with specimens of *Epinephelus fuscoguttatus*, also a monandric protogynous hermaphrodite species, collected from Australia's Great Barrier Reef [38]. In both *Epinephelus malabaricus* and *Epinephelus fuscoguttatus*, the mean size of males was significantly larger than that of females. However, some females were found in large size classes (in this study, one large female was found), indicating that perhaps not all females change sex [30]. This hypothesis could be tested in Tanzania by collecting

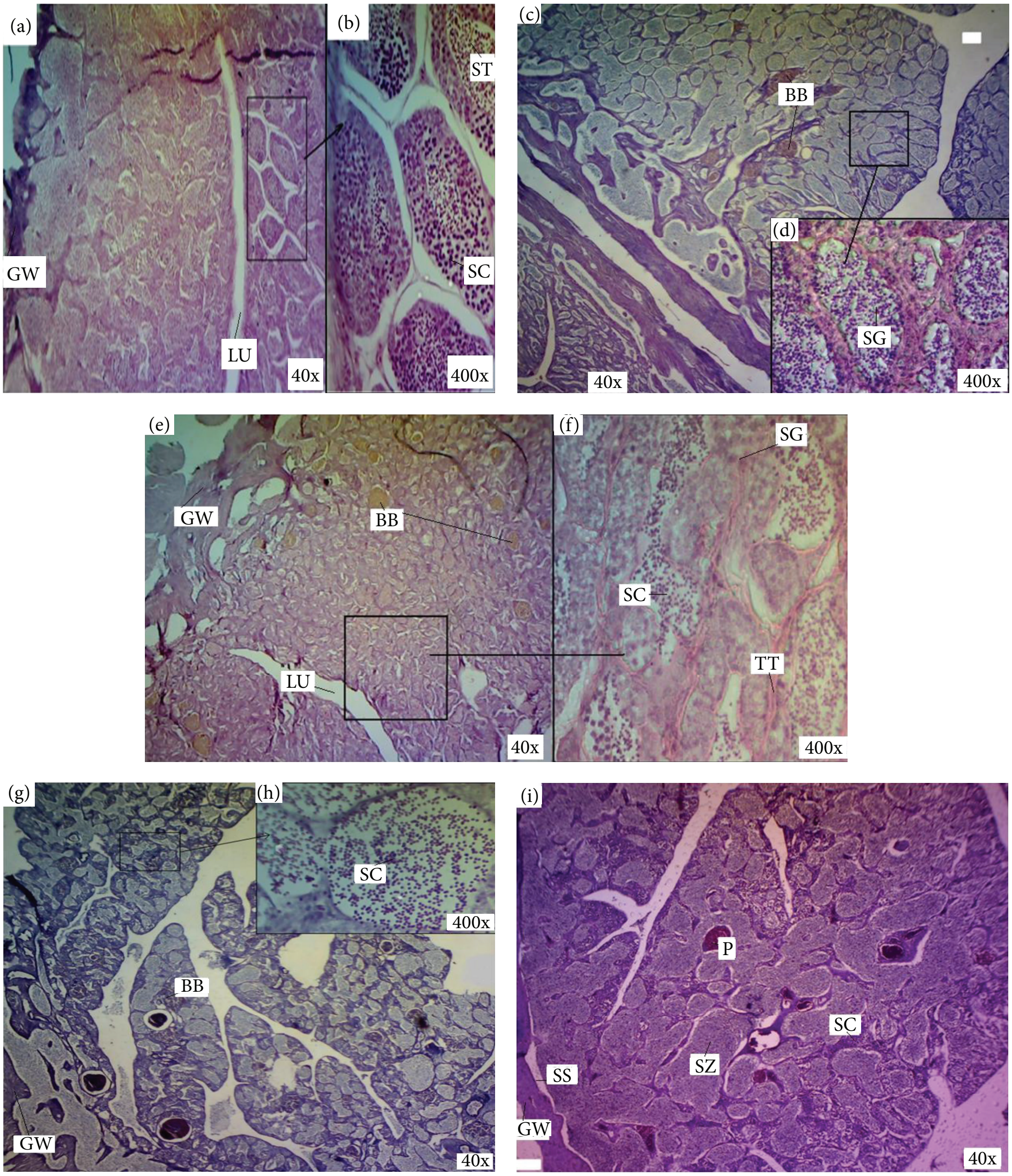

Figure 3: Histological sections of male *Epinephelus malabaricus* maturation stages of (a) mature ripening (M2) collected 1 February 2010, 97 cm L_T, 16 kg W_T, 20.66 g G_W; (c) resting male (M3) collected 20 February 2010, 109 cm L_T, 23 kg W_T, 39.11 g G_W; (e) resting male (M3) collected 28 February 2010, 100 cm L_T, 17 kg W_T, 39.53 g G_W; (g) mature ripening (M2) collected 23 January 2010, 105 cm L_T, 18 kg W_T, 26.87 g G_W; (i) mature ripe (M4) collected 9 September 2010, 103 cm L_T, 22 kg W_T, 68.86 g G_W. BB: brown bodies, GW: gonadal wall, G_W: gonad weight, L_T: total length, LU: lumen, SC: spermatocytes, SG: spermatogonia, SS: sperm sinus, ST: spermatid, SZ: spermatozoa, TT: testicular tissues.

a bigger sample size of larger specimens of *Epinephelus malabaricus* from different populations throughout the year.

The monthly assessment of sex ratios indicated that males outnumbered females in December, January, and February. This may have been biased by the fishing activities coinciding with calmer sea conditions, meaning that large groupers in deep reefs were more accessible and therefore more easily targeted. Fishery-independent data would therefore be required in order to determine whether or not the ratios obtained from the specimen samples collected from the fishers represent those of the grouper population. However, there are problems associated with obtaining such data in the waters around Mafia Island. For example, local fisher knowledge may be essential in understanding the techniques used for catching groupers and the seasonal influence of monsoon winds, which hinder access to deep reefs during rough seas.

In our samples, few juvenile specimens of less than 25 cm L_T were caught. Their absence in the samples collected is probably related to the selectivity of fishing gear that does not

TABLE 2: Monthly frequency and average length (cm) for *Epinephelus malabaricus* according to maturity stages. F1 and F2 are not included in female (F) : male (M) ratio. See Table 1 for descriptions of F1–F6 and M2–M5.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*N*	Mean length (cm)	SD	Min	Max	% of the total
F1	6	5	10	2	4	9	2	3	7	13	15	6	82	57.8	11.2	25	79	47.7
F2	2	2	1	1	0	0	0	0	1	3	2	1	13	69.8	8	59	79	7.6
F3	2	0	0	0	2	1	0	0	1	2	2	0	10	76.8	4.7	73	88	5.8
F4	4	1	0	0	0	0	1	0	1	3	2	2	14	82.9	6.7	71	90	8.1
F5	1	1	0	0	0	0	0	0	0	1	1	4	8	87.4	7.1	76	97	4.7
F6	0	0	0	0	0	0	0	0	2	1	3	3	9	89.1	11.1	80	113	5.2
M2	7	5	0	0	0	0	0	0	1	0	0	12	25	101.2	3.4	97	108.5	14.5
M3	2	0	0	0	0	0	0	0	0	0	0	1	3	104.8	3.4	102.8	108.7	1.7
M4	0	1	0	0	0	0	0	0	2	2	0	1	6	106.5	6.9	101	114	2.9
M5	0	0	0	0	0	0	0	0	0	0	0	2	2	111.7	1	110.6	112.3	1.7
F : M	1 : 1.3	1 : 3	—	—	2 : 0	1 : 0	1 : 0	—	1.3 : 1	3.5 : 1	8 : 0	1 : 1.8	1.1 : 1					

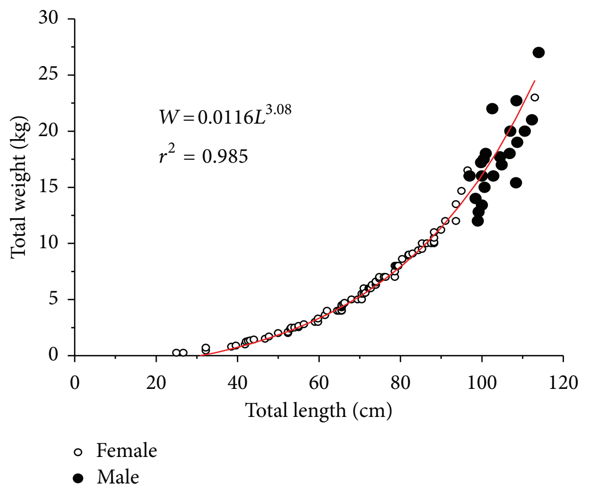

FIGURE 4: Length-weight relationship in *Epinephelus malabaricus* captured at Mafia Island between September 2009 and December 2010 ($N = 172$).

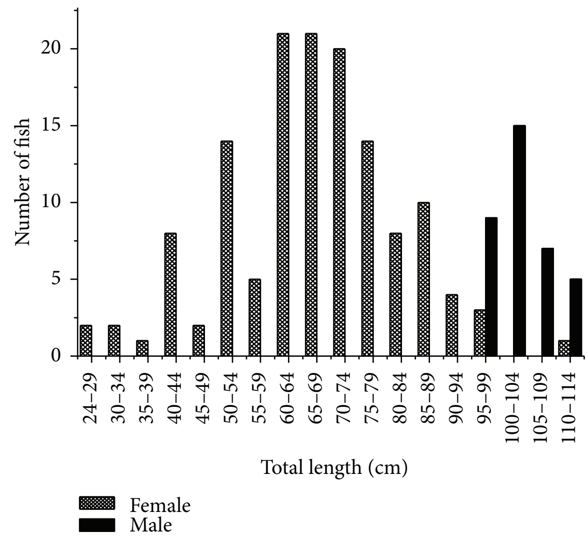

FIGURE 5: Size frequency distribution of female and male *Epinephelus malabaricus* ($N = 172$) collected from small scale fishers in Mafia Island between September 2009 and December 2010.

target juveniles, and perhaps also by their habitat preferences. It is possible that juvenile groupers occupy relatively rocky or coralline habitats [39] which are avoided by net fishers, or other structurally complex habitats like mangroves, in order to avoid predation.

Higher proportions of small and medium sized specimens were caught in shallow reefs, and large specimens were caught in deep reefs, which shows the depth stratification in size distribution [2, 40]. The bimodal size distribution according to depth may have several explanations. Perhaps it is related to gear selectivity, where small hooks and basket traps catching small fish are deployed in shallow waters, while only large hooks and basket traps catching large fish are deployed in deep water. Another reason for the size distribution could be related to oxygen levels in deep water being more favourable for large fish [41].

The maximum recorded total length for *Epinephelus malabaricus* is reported to be 150 cm [18], which corresponds to a weight of 53 kg. None of the specimens collected in this study had reached such a large size. The particularly large specimens are possibly less vulnerable to fishing due to inaccessibility at depth, while small and medium sized specimens are more accessible in the shallow reefs. Other reasons for smaller specimens could be related to consumers' preference at local and international levels, which motivates fishers to target smaller sized fish. In the villages where the study was conducted, large groupers used to be associated with devils (locally known as *chunusi*). We were told by one old fisherman, who was 70 years old, that spiritualists do not eat groupers because they consider them to be "princes of devils." Some people resist eating groupers with black dots (typical of *Epinephelus malabaricus*) for fear of acquiring similar dots on their skin. However, with the current economic and social changes occurring in the area, these traditional taboos are eroding. Young generations of fishers seem to ignore these taboos and actively target large fish for greater monetary reward. Moreover, they are more involved in surrounding-net fishing, an active form of fishing

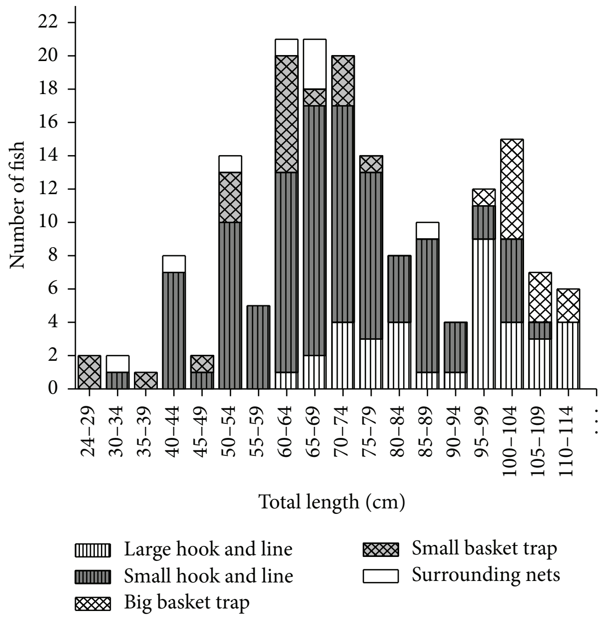

FIGURE 6: Length frequency distribution of the Malabar grouper *Epinephelus malabaricus* specimens caught by fishers using hook-and-line, basket traps, and surrounding nets between September 2009 and December 2010 around Mafia Island.

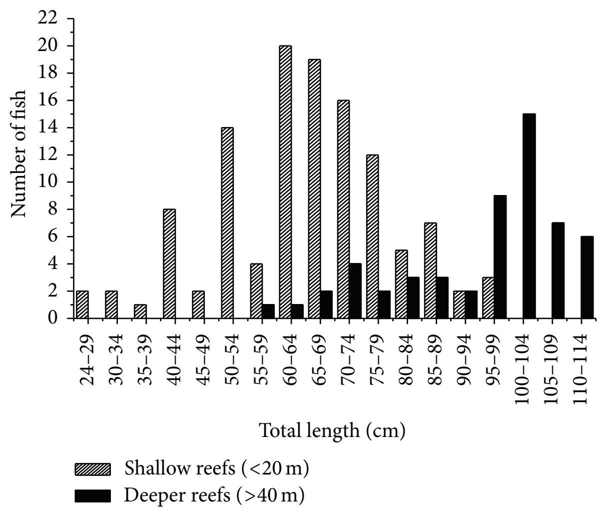

FIGURE 7: Number of *Epinephelus malabaricus* caught by small scale fishers at different reef depth profiles around Mafia Island between September 2009 and December 2010.

gear which is associated with a high yield in a relatively short period of time. They perceive handline fishing to be the work of old fishers, because it is time consuming, has a low yield, sometimes requires night fishing, and involves one or two people in an outrigger canoe.

On an international level, consumer preference is for smaller fish, because they do not like the taste of larger fish (C. Shekar, pers comm. February 2010). This motivates fishers to rather target small and medium sized fish and discourages them from targeting larger groupers. A group of fishers explained that they released large groupers (~>50 kg)

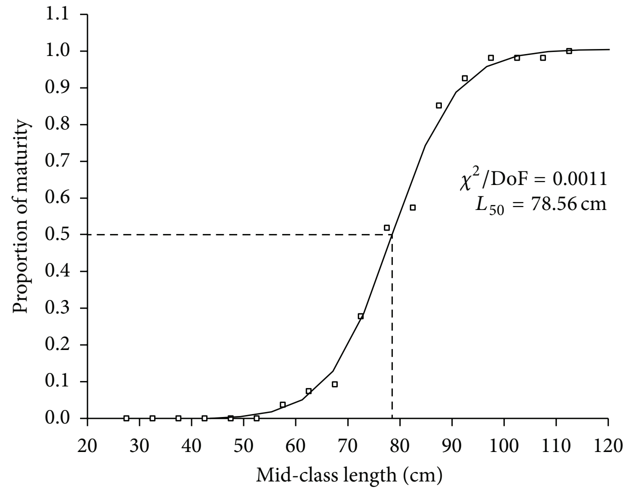

FIGURE 8: Proportions of sexually mature females (F3–F6) of *Epinephelus malabaricus* by L_T fitted to a logistic function (dashed line indicates the mean L_T at 50% sexual maturity (L_{50}) ($N = 143$).

that were caught in their basket traps because they are less marketable to the fish processing factories and the tourist hotels. Furthermore, larger fish take a longer time to sun-dry. These factors may render large *Epinephelus malabaricus* less prone to increased fishing pressure in the future.

4.2. Sexual Maturation. No evidence was obtained to confirm hermaphroditism based on the characteristics outlined by Sadovy and Shapiro [10], that is, either the presence of transitional specimens or the presence of atretic bodies in stages 1, 2, or 3 of oocytic atresia within testes. However, all the gonads of the immature specimens contained solely ovarian tissue, and a bimodal size distribution was apparent. The observed size distribution structure, with all small size specimens being female and the majority of large specimens being male, confirms that *Epinephelus malabaricus* is a monandric protogynous hermaphrodite species [11, 13, 42].

The size at 50% maturity in *Epinephelus malabaricus* females was estimated at 78.6 cm L_T. The results for L_{50} were within the same range (76.2 cm to 83.9 cm L_T) reported by Pember et al. [17] in north-western Australia. However, the L_{50} estimation depends on the number and size of the sample, the sampling period, and the criteria used for diagnosis. While maturity was estimated to occur in a wide size range, our data indicated that sex change occurred in a narrower size range (97 cm to 113 cm), showing that females change sex at their maximum size. Pember et al. [17] report that *Epinephelus malabaricus* change sex in the range of 105.5 cm to 114.7 cm L_T, which concurs with the range estimated in this study.

No transitional specimens were found in this study; therefore, we assume the size range to be within the overlap between mature females and the first size recorded for males. Males started to occur slightly below the size of 100% (112.8 cm) of female maturity, suggesting that they were secondary males, that is, all males are derived exclusively by sex change from adult females [43].

Neither spent nor resting females were found in this study. The reason for this may be the nature of the fishery,

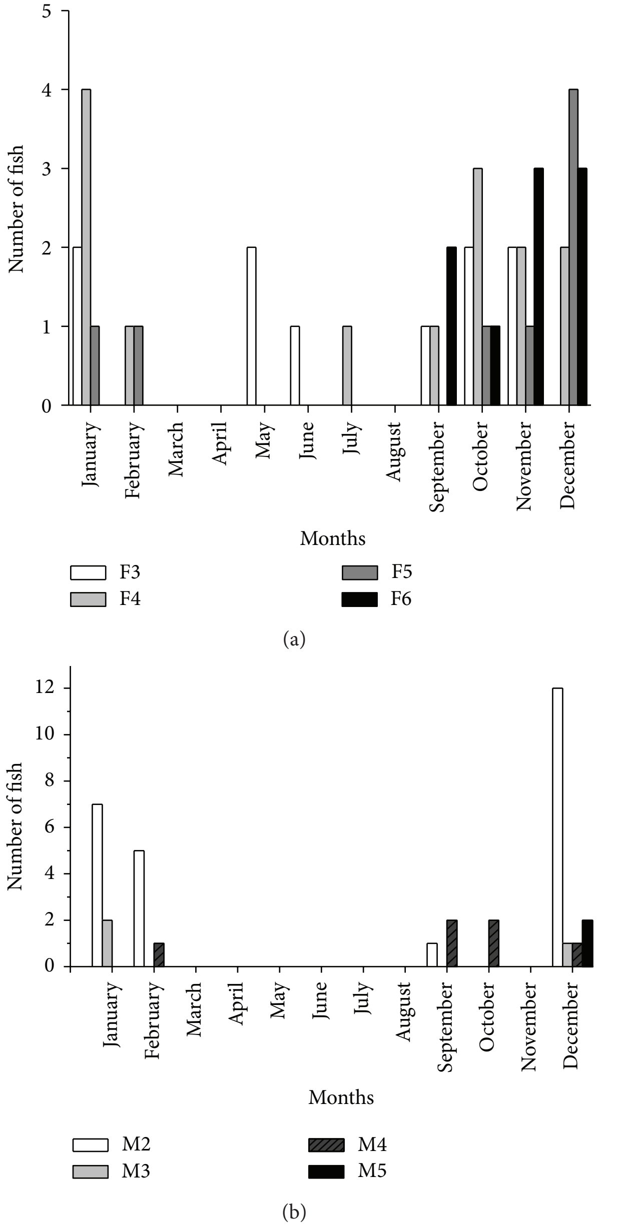

Figure 9: Monthly distributions of (a) female and (b) male *Epinephelus malabaricus* according to maturity stages.

whereby large sized specimens are restricted to deep reefs, which are not easily accessed by small-scale fishers. The accessibility of deep reefs is restricted to a few months (December to February) due to strong winds throughout the rest of the year. Therefore, the possibility of detecting sex change was affected by the lack of specimens caught from deep water during nonreproductive months. Shapiro [9] documents that sex change in some species of groupers is initiated during, or immediately after, spawning aggregations, but no observations or data are available as to whether *Epinephelus malabaricus* aggregate to spawn in the coastal waters of Tanzania.

4.3. Spawning Season of Epinephelus malabaricus. Based on gonadal histology, the prevalence of ovaries at stage F5 and F6 (ripe and mature running ripe) in September to February indicates that *Epinephelus malabaricus* spawned during these months for a protracted period. According to Shapiro [9], large species of groupers tend to spawn for one to five months each year. A long spawning season, coupled with the presence of oocytes at various stages in a mature female, suggests that females spawn repeatedly during the breeding season [29, 44]. The advantage of spawning occurring between September and February may be to enable hatched larvae to utilise the food made available by the increased abundance of plankton in Tanzanian waters at this time of year [26]. This concurs with the information obtained from elder fishers in the area, who believe that fish do not spawn, but come with the rains. One old fisher told us that "... Fish do not reproduce, they are brought by God and fall with the rains" (H. Ngwali, pers comm; interview no. 15, January 2010). It is possible that fishers have observed juvenile groupers in shallow waters during the rainy seasons (March to May).

Males showed no conclusive evidence of the spawning season since they did not exhibit large changes in gonadal weight. Furthermore, few male specimens were caught, with none being caught between March and August. This period is characterised by low surface water temperatures, when most fish come to shallow waters for feeding (pers. comm. with fishers). It may be that males of *Epinephelus malabaricus* do not come to shallow waters; due to their large size they stay offshore in deep reefs with more favourable oxygen levels [41].

The spawning season of *Epinephelus malabaricus* found in this study coincides with the calm conditions of the sea, which allows fishers to access deep reefs offshore. This period is associated with the grouper fishing season; however, it is not known whether fishers are targeting spawning aggregations. All interviewed fishers said that groupers do not aggregate in large numbers. Some species of grouper (*Epinephelus polyphekadion, Epinephelus fuscoguttatus*, and *Plectropomus punctatus*) have been reported to spawn in large numbers at specific locations and times in East Africa, which makes it easy for fishers to locate them [45]. Fishers' lack of awareness about spawning aggregations is possibly due to *Epinephelus malabaricus* migrating greater distances to spawn in deeper water [44], thus making them inaccessible to fishers. A further study would be required to verify the timing and location of the *Epinephelus malabaricus* spawning season.

5. Conclusions

Based on the biological findings in this study, the observed size distribution structure, whereby all small size individuals are female and the majority of large individuals are males, confirms that *Epinephelus malabaricus* is a monandric protogynous hermaphrodite species. The minimum landing weight of 2 kg proposed for the trial policy on groupers exports corresponds to immature *Epinephelus malabaricus* of less than 60 cm L_T which are not yet capable of reproducing; therefore, in order to ensure the survival and continued reproduction of the species, the stated minimum size limit needs to be reconsidered. The spawning season is from

September to February, which coincides with the grouper fishing season, but this particular species is not known to have spawning aggregations. The *Epinephelus malabaricus* fished in Mafia Island waters include a range of immature specimens, ripe females and few large males; this seems to be a non-selective fishing pattern achieved by using gear of different types and sizes, which may contribute to ensuring the viability of *Epinephelus malabaricus* populations.

The deep reefs where large specimens of *Epinephelus malabaricus* are fished are found mainly outside the Mafia Island Marine Park area. Furthermore, there are no national fishing regulations stipulating the minimum or maximum size of grouper species that can be caught, the size of hooks and basket traps that may be used or the best time of year to catch groupers so as to avoid affecting their spawning activities. The natural seasonal closure of fishing due to strong southeast monsoon winds, coupled with the small size of fishing vessels and gear used by resident fishers, hinders access to deep reefs. These factors are currently acting as natural limitations to the fishing of large *Epinephelus malabaricus*. Another factor limiting the pressure on large fish is the consumer preference for smaller fish, at both local and international levels.

However, with the current and envisaged expansion and development interventions in the fishing industry, with the market focusing on the exportation of fish products, we anticipate that the number of fishers coming to Mafia Island to catch groupers may increase. The reason for increased numbers of fishers targeting groupers might be that groupers often weigh more than other demersal species; hence they yield more significant economic gains. Other reasons could be the improved access to fish markets (e.g., the presence of fish processing factories exporting fish products), the lack of alternative employment which leads to heavy dependence on fish resources, the exhaustion of fish resources in other parts of Tanzania, and the lower abundance of reef fish in the waters of the western side of Mafia Island. Therefore, fisheries management strategies need to reconsider the above aspects of the biology and ecology of *Epinephelus malabaricus* and adopt a precautionary approach, paying close attention to fishers' traditional knowledge and encouraging genuine involvement in decision making by the fishers who are dependent on the industry.

Acknowledgments

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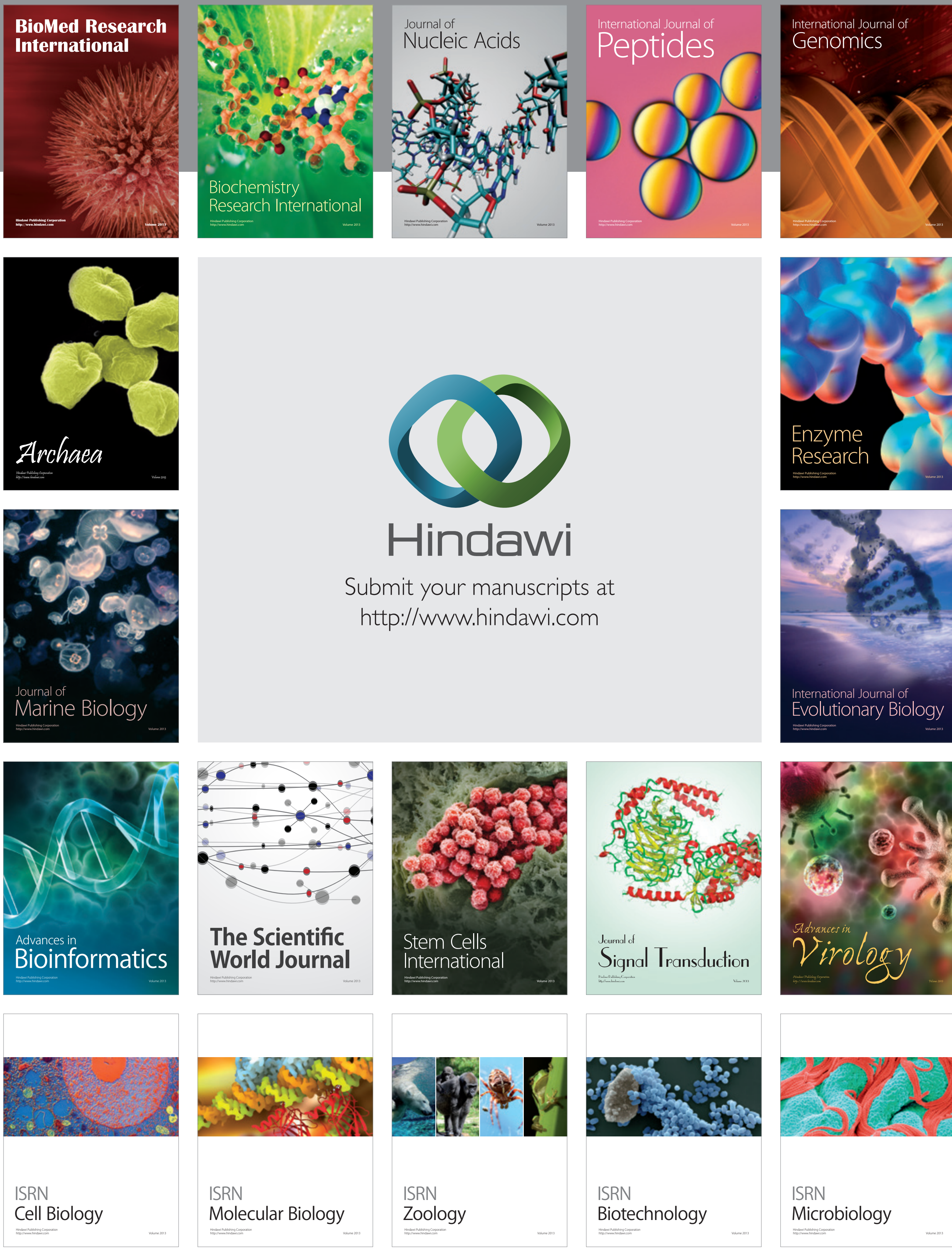
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ISRN Zoology
ISRN Biotechnology
ISRN Microbiology

Erratum

On page 3 sub-section 2.2. words ‘to the nearest 1 cm, 1 kg and 0.01 g’ should be replaced with ‘in cm, kg and g’ respectively.

PAPER III

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Complementarity of fishers' traditional ecological knowledge and conventional science: Contributions to the management of groupers (Epinephelinae) fisheries around Mafia Island, Tanzania

Lydia Gaspare [a, b, *], Ian Bryceson [a], Kassim Kulindwa [a]

[a] Department of International Environment and Development Studies (Noragric), Norwegian University of Life Sciences, 1432 Aas, Norway
[b] Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, P.O. Box 60091, Dar es Salaam, Tanzania

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ABSTRACT

Traditional ecological knowledge (TEK) is increasingly advocated as a complementary source of information that can potentially be integrated into mainstream science, particularly to help improve fisheries management. However, less attention has been paid to identifying specific areas where the TEK of fishers may confirm or contradict conventional scientific knowledge (CSK); or where TEK may provide new insights for fisheries systems characterized by multi-species and multi-gear usage. We conducted a qualitative exploration of TEK of grouper fishing patterns and compared the findings with an analysis of catch data in order to elucidate the extent of fishing pressure on groupers. We further compared TEK of the ecology and biology of groupers with published CSK to understand the complementarity between the two domains. Data collection methods included structured open-ended questionnaire, semi-structured interviews with key informants, focus group discussions, personal observations and a literature review. Results indicate that TEK complements CSK in terms of catch assessment and the ecology of groupers. TEK provides additional information on fishing gear, specific grouper species caught, habitat use and feeding habits; however, TEK contradicts CSK regarding spawning aggregation behavior. TEK offers new knowledge on environmental threats facing groupers, but fishers lack knowledge on reproductive modes and life history traits (i.e. hermaphroditism and spawning season) of groupers. We conclude that, in a conducive democratic setting based upon mutual respect and trust, TEK can complement conventional science and help to make more informed management decisions for sustainable fishing.

1. Introduction

Integrating fishers' traditional ecological knowledge (TEK) with conventional scientific knowledge (CSK) is strongly advocated as the most feasible option to manage coastal fisheries utilized by small-scale fishers (Johannes, 1998; Berkes et al., 2001; Berkes, 2003, 2012; Haggan et al., 2007; Thornton and Scheer, 2012). Yet Hind (2014) argues in a recent paper that compared to conventional methods used in fisheries science, the contribution of fishers' local knowledge is lagging behind. In this paper, fishers' TEK is understood to be a "cumulative body of knowledge and beliefs about the relationship of fishers to the local marine environment in which they live, as well as their local fishing practices for ecosystems use and stewardship" (Berkes, 1993, p. 3). CSK refers to knowledge from observations by fishery scientists and managers using more conventional 'hard' data derived from scientific studies and theoretical interpretations (Mackinson, 2001). According to Johannes (1981), Sutherland et al. (2014) and Tengö et al. (2014), knowledge held by local users of the marine environment is of great value, especially in understanding patterns of resource utilization for effective management and long-term sustainability. Evidence from empirical studies shows that many conventional management regimes have failed (e.g. biologists failing to predict inshore fishery dynamics) due to ignoring fishers' TEK in monitoring and decision making processes (Johannes, 1981; Hilborn et al., 1995; Johannes et al., 2000; Berkes et al., 2001; Castilla, 2001). Likewise, top-down management systems and regulations based on

* Corresponding author. Permanent address: Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, P.O. Box 60091, Dar es Salaam, Tanzania.
E-mail addresses: lgaspare@yahoo.co.uk (L. Gaspare), ian.bryceson@nmbu.no (I. Bryceson), Kassim.kulindwa@nmbu.no (K. Kulindwa).

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information from conventional science, without allowing the participation of local fishing communities, have failed or experienced a lack of compliance (Jentoft, 2000; Castilla, 2001; Almudi and Kalikoski, 2010).

To date, many researchers have recognized and used TEK for various purposes, such as studies on fisheries assessment (Neis et al., 1999; Bender et al., 2013), taxonomy of marine organisms (Berlin, 1992; Drew, 2005; Ramires et al., 2012), fish spawning aggregation (Robinson et al., 2004; Samoilys et al., 2006; Hamilton et al., 2011), and design of conservation and fisheries management measures (Friedlander et al., 2003; Drew, 2005; Baird, 2007; McClanahan et al., 2009; Masalu et al., 2010). Furthermore, several studies have focused on the differences between fishers' TEK and CSK, while recognizing the complementarity between these two knowledge systems in the management and conservation of aquatic ecosystems (García-Allut et al., 2007; Johannes and Neis, 2007; Silvano et al., 2008; Jackson et al., 2014). However, few researchers have attempted to examine fishers' TEK in relation to CSK of harvestable fish species for sound fisheries management (Silvano and Valbo-Jørgensen, 2008).

In a developing country like Tanzania, small-scale fishers rely on TEK in their daily fishing activities, gained through practice and observations over time and passed on through generations, from old to young fishers. Fishers make their living by seeking fish in coastal ecosystems characterized by dynamism, complexity and habitat heterogeneity (Silvano and Valbo-Jørgensen, 2008). In particular, small-scale fishers target many species of fish from various habitats, using multiple fishing gears at different times of the year. Where they face dwindling fisheries resources, fishers adapt to changing circumstances. The focus of this study is groupers (family *Epinephelidae*), which are among species of fish targeted by small-scale fishers in Tanzania coastal waters.

Groupers were selected for this study because they are top predators, playing a major role in structuring coral reef ecosystems. Randall (1987) and Sadovy de Mitcheson et al. (2013) observed that groupers are heavily utilized for commercial purposes and for consumption worldwide. Moreover, many species of groupers are listed on the International Union for Conservation of Nature (IUCN) red list as threatened or near threatened species (Cornish, 2006). Tanzania lacks complete information needed to manage coastal fisheries effectively; in particular, fishers' TEK about grouper species, their ecology and biology, and fishing patterns is poorly understood by scientists and fisheries managers. On this basis, we argue that, in addition to the basic principle of collaborative use of TEK and CSK in fisheries management, fishers' TEK provides an opportunity to advance knowledge and provide new information on the ecology and biology of groupers. Furthermore, understanding local fishing practices may help to identify priorities for fisheries management and suitable interventions to assist fishers and avoid conflicts between stakeholders, thus ensuring resource sustainability.

The present study is aimed at elucidating areas in which both TEK and conventional scientific study could contribute information required for effective fisheries management and the conservation of groupers. Two main research questions are addressed: 1) How does fishers' TEK compare or contrast with CSK? 2) What lessons can be learned towards improving the management of grouper fisheries in Mafia? Answers to these questions will form the basis for establishing collaborative engagements between fishers, conventional scientists and managers, in order to deal with challenges in fisheries management and socio-economic problems.

2. Materials and methods

2.1. Study sites

Mafia Island and its small islets are located approximately 120 km southeast of Dar es Salaam and 20 km offshore from the eastern extent of the Rufiji Delta. The island is about 48 km long and 17 km wide at its widest point. It has a population of 46,438 according to the 2012 census, and an area of 413 km^2. The sheltered western side is influenced by sedimentary materials discharged from the Tanzanian mainland via the Rufiji River. The eastern side is exposed to the full force of the Indian Ocean waves and currents and is characterized by a 33 km outer fringing reef along the eastern seaboard. The continental shelf is narrow and falls to depths of over 1000 m within a few kilometers from the island. This study was conducted in the southern part of the island (Fig. 1) which is under conservation control by the Mafia Island Marine Park (MIMP). The MIMP was established in 1994 and started operations in July 1995.

The Marine Park was created in order *inter alia* to provide for the conservation of marine biodiversity, to promote the sustainable utilization of marine resources, and to enable the rehabilitation of damaged ecosystems (URT, 2011). The park is a multiple-use facility where human settlements have been allowed to remain – over 50 percent of the population of Mafia lives within the MIMP boundaries. In order to address conflicting interests between user groups, a zoning plan was adopted, including no-take, specified-use and regulated-use zones. Zones have different regimes of protection and permitted activities, depending on the importance to conservation and economic activity of the areas designated under each zone (URT, 2011).

The area under conservation covers 822 km^2, of which 75% is below the high water mark and more than 50% is less than 20 m deep (McClanahan et al., 2008). The two monsoon winds, and the north flowing East African Equatorial Current influences the climate of the area, with dry and rainy seasons, and warm and humid conditions throughout the year. The sea surface temperature ranges from 25 °C to 31 °C. March to May is a period characterized by heavy rainfall, June to August is a cool and dry season. Scattered showers occur in August and September, and short rains fall from October to December.

Fishing activities in Mafia follow the Arabic calendar and are controlled by two distinct seasons (Table 1). The period from December to March is a period of calm sea, when the northeast monsoon blows. At this time of the year, all types of fishing are practised due to ease of accessing the outer reefs. After a short period of transition, the southeast monsoon follows in the months from April to September, characterized by strong winds which hinder access to the outer reefs. Low fishing intensity occurs between June and August, a period coinciding with peak southeast monsoon winds characterized by high wind energy, the strong East African Coastal Current and lower temperatures. During this period, most types of fishing are concentrated inside Chole Bay. Moreover, this period coincides with the farming season, when Juani fishers need to guard their farms against vermin animals like the wild pig. From September to November is a transitional period, when intermediary winds allow infrequent fishing on the outer reef.

2.2. Data collection

Data on fishers' TEK presented in this paper were collected as part of a wider study assessing the linkages between social and ecological aspects of grouper fisheries in Mafia Island that was conducted from August 2009 to March 2011. Catch data were extracted from data collected by the MIMP in monitoring the performance of the marine park. Before our own data collection, we presented and discussed the objectives of the study with respondents in each village. The first author administered the questionnaire and conducted all the interviews. The interview data was collected in three parts. In the first part we selected 16 resident

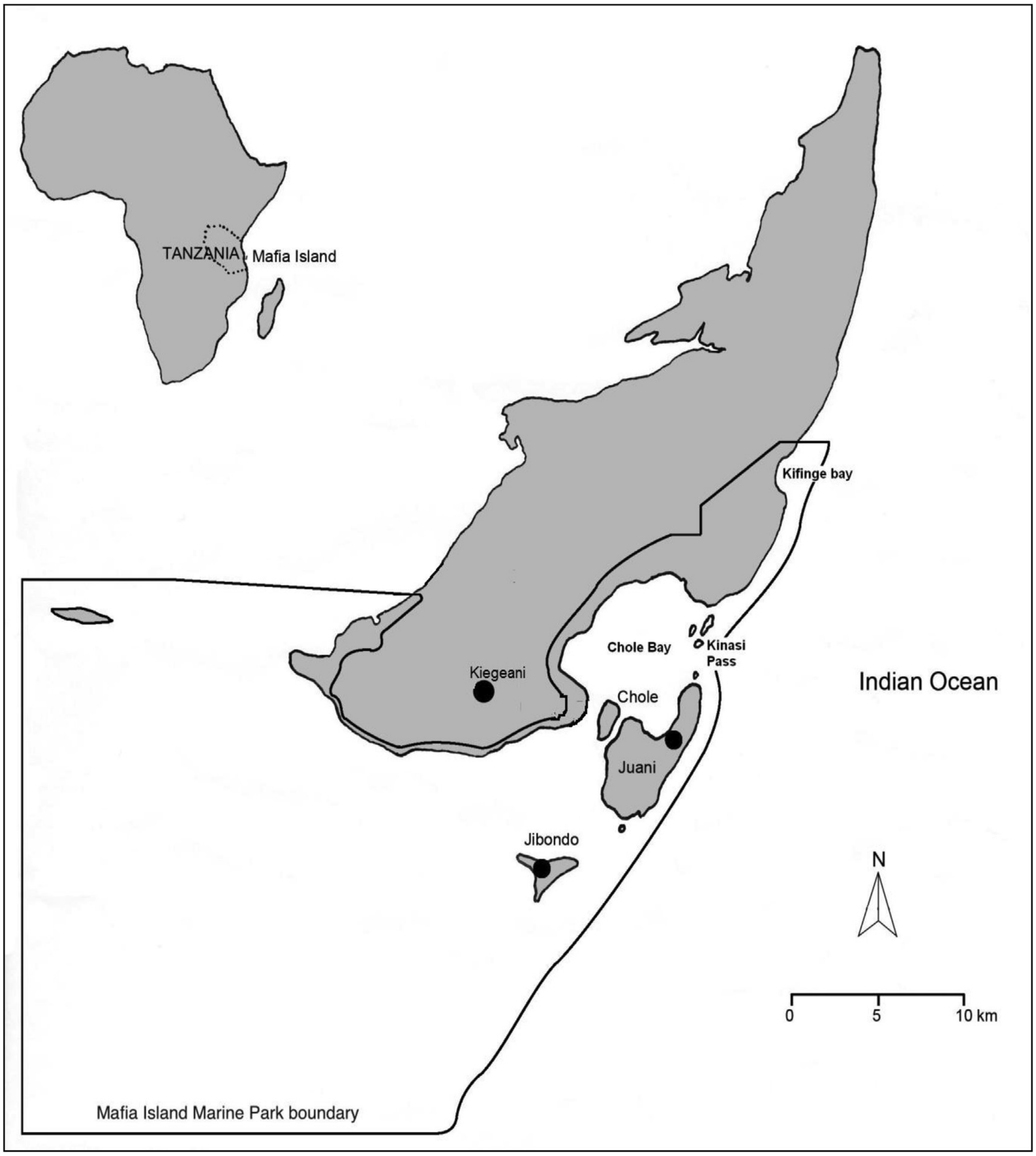

Fig. 1. Map of Mafia Island, Tanzania, showing the villages of Kiegeani, Chole, Jibondo and Juani, where fishers were interviewed.

Table 1
Generalized seasonality calendar of fishing practices constructed by community members in Juani and Kiegeani.

Gregorian calendar	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Arab calendar 2011 (*Mfungo*)	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Shabani***	***Ramadhani***	**1**	**2**	**3**
Monsoon wind	northeast monsoon			intermediate		southeast monsoon			intermediate easterly winds		northeast monsoon	
Access to outer reef												
Access to inner reef												
Rainy season			long rains						short rains			
Farming season												
Handline fishing												
Basket trap fishing												
Gill-net fishing												
Seine-net fishing												
Grouper fishing												

Note: White – not practiced Light grey – lightly practiced Dark grey – intensively practiced

(Fishers who were born in Mafia or elsewhere but have lived inside the marine park boundaries for more than 10 years) fishers and obtained their prior and informed consent. We identified these key informants based on advice and recommendations from community leaders and other fishers in the villages of Kiegeani, Chole, Jibondo and Juani. The key informants were regarded by the community as knowledgeable about groupers because of their fishing methods (handline, traps and shark net), as well as having spent more than 20 years in fishing. The selected informants were interviewed independently about the ecology and biology of groupers found in Mafia waters. The main questions posed focused on the major species of groupers known to fishers, habitat preferences, feeding habits, reproduction and spawning behavior, and threats to groupers. Fishers' were asked the types of grouper species they know. Together with the fishers, we identified groupers mentioned with the aid of a field guide book (Lieske and Myers, 2001) and photographs of recently caught and identified groupers. Interviews took place outside fishers' homes, at fish landing sites, on the beach, or in the community center in the morning or evening after they had completed their fishing activities. Interviews were conducted in Kiswahili and lasted between 50 and 90 min.

In the second part of data collection, 61 resident fishers were randomly sampled from two communities (28 from Juani and 33 from Kiegeani), and interviewed using a structured open-ended questionnaire. The questionnaire was pretested prior to the interviews, to control validity and modifications were made where necessary to enhance its utility in addressing relevant issues. The interviews inquired about traditional fishing practices and patterns related to catching groupers, in particular the use of fishing gear, fishing vessels, and fishing grounds. Questions were posed to each respondent, such as "What are the most common grouper species that you catch?"; "Is there a seasonal pattern in catching groupers?"; "Where do you catch them? (fishing grounds)". Determining the grouper species caught most was based on a list of species that were pre-identified by researchers. Photographs were shown to fishers in random order to increase reliability, which is a standard method adopted from Silvano and Begossi (2002).

In the third part, two group discussions were held in each community. Groups for mapping the fishing grounds consisted only of fishermen because women do not participate in finfish fishing. Groups for constructing fishing calendars consisted of both men and women because it incorporated land-based activities handled by women. We also conducted a one day participatory exercise to map fishing grounds with a team of three knowledgeable fishers selected from the two communities. These three fishers were identified with the help of community leaders and other fishers. Before we mapped the fishing sites, we explained the aim of the exercise so as to obtain their consent. We agreed not to publish the exact positions of fishing sites in-order to avoid competitive advantage in knowing the location of the sites. At each fishing site we recorded the depth, the distance from the beach and the benthic type. In addition, our boat driver (a retired fisher from the village of Kiegeani) provided detailed information regarding grouper fishing around Mafia Island. Results were validated through field observation during the entire fieldwork period of eighteen months (November 2009 to March 2011). The researcher followed fishers' daily activities, including social events, community gatherings and meetings. Unfortunately, she was not able to participate in fishing activities in order to gain an insider view, because women are not allowed to touch fishing gear for cultural reasons.

2.3. Data analyses

Descriptive statistics were used to analyze responses from fishers and results are presented as counts and percentages. Content analysis was used to analyze qualitative data (Bryman, 2008). The qualitative analysis of information was started by identifying major themes while collecting data from the focus group discussions and key informant interviews, and it ended with an in-depth description of the findings. Factors influencing the different aspects of fishing practices are listed in this paper according to the emerging themes, presented as percentages, and illustrated using direct quotes from key informants. The percentage of fishers who responded to the questions regarding fishing practice is used to indicate the extent to which fishing pressure is perceived among the two fishing communities and users of different fishing gear. Some questions have a total of more than one hundred, where fishers provided more than one answer at a time, for example, reasons for using a particular type of fishing gear (Table 3). Kruskal–Wallis test using MINITAB software (version 14 for Windows) was used to determine the difference in grouper catch (kg^1 $fisher^{-1}$ day^{-1}) among fishing sites and fishing seasons at the 5% level of significance.

3. Results

3.1. Fishers, fishing methods and types of gear

3.1.1. Profile of fishers interviewed

All the fishers interviewed were male, ranging in age from 24 to 80 years (average 45 years), with fishing experience ranging from 2 to 70 years (average 26 years) (Table 2). About 33% of handline fishers started fishing at the age of 10 years. Although all children are required to attend primary school, some children under 10 conduct handline fishing in the evenings after school.

The survey results on the acquisition of fishing skills show that 75% ($n = 61$) of respondents had fisher parents, 84% of them learnt fishing by accompanying elders to fishing activities; and 16% ($n = 61$) taught themselves. When asked how they acquired new fishing techniques, the majority (79%, $n = 61$) of fishers said that they have not learnt any new fishing techniques from outside Mafia. Their ongoing learning is based on their own creativity, trial and error, and by modifying traditional gear, depending on the situation. They continue to learn from experienced fishers and by observing fellow fishers who come from other parts of Tanzania to fish in Mafia. Three fishers mentioned that they had received formal training on new fishing techniques by the MIMP. However, they claimed that the training was not effective because it was for a short period and was done on unfamiliar fishing grounds outside Mafia, using gear that was not effective.

Concerning residence status, most fishers (70%, $n = 33$) interviewed in Kiegeani had immigrated from other parts of Tanzania and islets of Mafia, and had lived in the village for an average of 25 years. Reasons for immigration included their quest for coconut farming areas to avoid economic dependency on fishing, the attraction of abundant fish in Mafia waters, employment opportunities in tourist hotels, the lack of reliable water availability in other parts of Mafia, and the sheltered nature of the Chole Bay seascape. Decisions regarding becoming a fisher were influenced by socio-economic and cultural factors. These include, amongst other factors, the lack of alternative employment, the lack of formal school education, or not having been selected to continue with secondary education. Furthermore, our results show that fishing is the main income source for most fishers in Juani (89%, $n = 28$) and Kiegeani (70%, $n = 33$), and that most fishers in Juani (61%, $n = 28$) and less in Kiegeani (40%, $n = 33$) do not have other sources of income.

3.1.2. Selection of types of fishing gear

Important fishing gear used to catch groupers are hook-and-

Table 2
General characteristics of fishers interviewed.

Variables	Description	Kiegeani (n = 33)	Juani (n = 28)
		Frequencies (%)	
Age	20 years or younger	–	–
	21–35 years	27	29
	Older than 36 years	73	71
Fishing experience	10 years or less	18	14
	11–35 years	61	57
	More than 35 years	21	29
Place of birth	Mafia	73	96
	Elsewhere	27	4
Education	No formal education	18	21
	Primary school	76	79
	Secondary school	–	–
	College	6	–
Main source of income	Fishing	70	89
	Farming	24	11
	Other (petty trade, casual job)	6	–
Use of outboard engine	Yes	9	46
	No	91	54

lines, basket traps, shark net and nets (Table 3). Based on interviews with fishers, their choice of gear generally depends on various factors, such as economic (54%), technical (43%), social (31%) and environmental (8%) (Table 4). Handlines and basket traps are used predominantly, due mainly to their affordability. Other reasons for selecting handline and basket trap are expertise and experience with the equipment, flexibility in doing other activities on land and the age of a fisher. Fishing vessels types used include dugout canoe, outrigger canoe and wooden planked boats.

3.1.3. *Factors for the selection of fishing sites*

The selection of locations to deploy fishing gear depends on the fishers' knowledge of fish habitats, the availability of fish, and to some extent, previous experience with traditional sites. For deeper sea areas, fishers have developed ways of knowing the nature of the seabed. These indicators include knowledge of fish species caught on earlier visits, the speed of the water current, and sending the anchor down to the seabed. Other factors which influence the selection of a fishing site are the age of a fisher, the possession of an outboard engine, knowledge and access to information about grouper catch rates, fishing experience and marine park regulations (Table 5).

The results of the examination of fishing grounds that are avoided at various times of the year (northeast monsoon and southeast monsoon) indicate a clear difference between two fishing locations (outer reef and inner reef) for users of different fishing gear (Fig. 2). During the southeast monsoon when the sea is rough, fishers avoid the outer reefs. Three shark net fishers responded that they migrate to places where the sea is calm. During the northeast monsoon season, the inner reefs experience the same fishing effort from handline and basket trap fishers because of their small fishing vessels that limit them from going offshore. Shark net fishers avoid inshore areas and net fishing is conducted in both fishing grounds, depending on the size of vessel and mode of propulsion.

Fishing trip frequencies are influenced by tidal cycles, land based activities (for example, farming), gear and vessel maintenance, time to attend to family matters, health, social–cultural activities (for example, weddings, bereavement) and the availability of fish. Furthermore, fishers stated that the daily fish catch is affected by lunar cycles, currents and clouds. Fishers have many ways of predicting weather conditions that affect daily fishing activities, such as strong winds or rain. Such signs include the color of clouds, the magnitude of waves at sea, colors of sunset and sunrise, the appearance of stars at night, and dew in the morning. As explained by one handline fisher:

"Fish predict and sense changes in weather – if it is cloudy, fish caught by hook-and-line do not eat bait effectively; you can go fishing and won't catch a single fish, or just get two fish. But if the

Table 3
Fishing vessels and types of gear used by small-scale fishers in Mafia.

Types of fishing gear	Description	Kiegeani (n = 33)	Juani (n = 28)
		Frequency (%)	
Hook-and-line	Nylon monofilament line no. 40–300 and hook no. 1–15	33	7
	Long-line big hooks (size not specified)	–	–
Basket traps	Small – 0.5 × 0.4 × 0.15 m with a mesh size of 3 cm,	18	21
	Big – 1.06 × 0.61 × 0.30 m with a mesh size of 8 cm	–	–
Shark net	18 ply rope, >3 inches stretch mesh size, 10–12 m wide and 40–100 m long	15	7
Harpoon	No specific size, commonly observed in each vessels	–	4
Net[a]	2.5 inches stretch mesh size (Average size of set-net is 22 m long and 4 m wide, pull-net is 50 m long and 6 m but modified according to water depth. The scope net is 0.5 inches mesh size, 5 m long and 4 m wide.	33	61
Vessel type (Average length = 6 m)	Dugout canoe (paddling and sail)	27	21
	Outrigger canoe(paddling and sail)	42	25
	Wooden planked boats (sail and outboard engine	15	50
No vessels	By foot	15	4

[a] Include surrounding net, pull net, set net, *Msembwe* (gill net fishing operated in intertidal areas without using a fishing vessel) and *Mbadala* (gill net fishing operated in intertidal areas and set to encircle a patchy reef. Fishers beat water to scare fish. This practice is discouraged by MIMP).

Table 4
Fishers' multiple responses (%) to the question: "Why do you use such fishing gear?" Reasons provided by fishers are divided into sections for simplicity.

Factors	Fishing gear types			
	Handline (n = 14)	Basket traps (n = 12)	Shark net (n = 7)	Net (n = 28)
Economic				
- Affordability of the gear	54	42	–	18
- Flexibility in doing other activities on land	15	42	–	7
- Maximizing catch, income and profit	8	–	25	18
Technical				
- Expertise and experience with the gear	46	17	–	29
- Amount of time taken fishing	–	17	–	4
- Number of crew required to operate the gear	8	–	–	4
- Selection of fish in terms of size	8	–	25	–
- Locating a fishing ground	8	–	–	4
- Ability to dive				4
Social and cultural				
- Fisheries regulations	8	8	25	29
- Age and health issues	8	17	–	–
- Friendship, family and class practices	8	8	–	–
Environmental				
- No damage to environment	–	–	25	11
- Sea conditions	8	–	–	–

sky is clear with no clouds, fish eat bait and the catch increases …"

According to testimonies from respondents, fishers have developed ways of increasing the daily catch. These include diving to depths of up to 10 m to cover traps with pieces of dead coral and rocks to make a cave-like structure that groupers find attractive; increasing the number of traps; setting traps in areas where fish tend to feed; setting traps at different sites; and placing bait in traps. However, the small size of vessels commonly used by trap fishers prevents them from carrying too many traps. Fishers' knowledge of fish movements according to tidal cycles determines where and when to set traps. During neap tide, basket trap fishing is minimal because at low tide, the water depth is high and fish are dispersed. At this time, fishers either engages in other activities on land, such as farming (February to May is a period to protect farms from vermin), adopt handline fishing, or repair fishing vessels. Likewise, handline fishers have developed ways of increasing their catch, such as the use of various types of bait (fish, octopus, squid and moray eels), fishing far offshore on the outer reef, fishing at night (the time that fish feed), and norms of behavior such as bathing after sex before going fishing.

3.2. *Patterns of grouper fishing*

3.2.1. *Grouper species caught by various types of gear*

Results from gear users responding to a question about type of grouper species caught, indicate that all types of fishing gear catch sedentary, small sized grouper species (Fig. 3), with the exception of shark nets. Large species (*Epinephelus coioides, Epinephelus malabaricus* and *Epinephelus lanceolatus*), and deepwater species (*Cephalopholis aurantia*) were mentioned less frequently by all gear users. Comparable catch data about specific species of groupers caught in Mafia were not available. Further, there are no national fishing regulations that stipulate the minimum or maximum size of grouper species that can be caught.

Four out of seven shark net fishers reported catching *Epinephelus fuscoguttatus* which is a large aggregating grouper; however shark net fishing is expensive and few people can afford it. Furthermore, fishers stated that shark net fishing is associated with many problems that reduce the number of possible fishing days. These problems include low quality nylon ropes required for mending nets, nets getting entangled in coral, nets being swept away by currents, and low fish catch. Other problems are of a superstitious nature, for example, fishers believing that people may bewitch each other by 'cursing' their fishing gear to prevent them from catching fish. According to fishers' testimonies, curses can cause a total loss of income, because fishers spend money cleansing their nets from witchcraft. However, further studies are needed to understand the impact of such curses on fishers' practices.

3.2.2. *Fishing location for groupers*

Responding to the question: "Where are groupers mostly caught?", the majority of handline (75%, n = 14) and shark net (100%, n = 7) fishers said groupers are caught mostly in outer reefs; while net (52%, n = 28) and basket trap (42%, n = 12) fishers said

Table 5
Fishers' multiple responses (%) to the question: "Why do you fish where you fish?"

Factors	Handline (n = 14)	Basket trap (n = 12)	Shark net (n = 7)	Net (n = 28)
Nature of seabed and topography (coral reef/sea grass/sandy)	69	77	33	38
Water depth	23	46	17	10
Water currents	–	–	–	14
Tidal cycles	23	15	17	34
Availability of fish	69	8	67	34
Catch history	62	–	17	3
Weather	31	–	33	7
Experience with traditional sites	46	8	50	21
Guessing	38	–	–	–
Number of crew members	–	8	–	–
Distance from home	–	15	–	10
Avoid conflict with other fishers using different gear	–	8	–	–

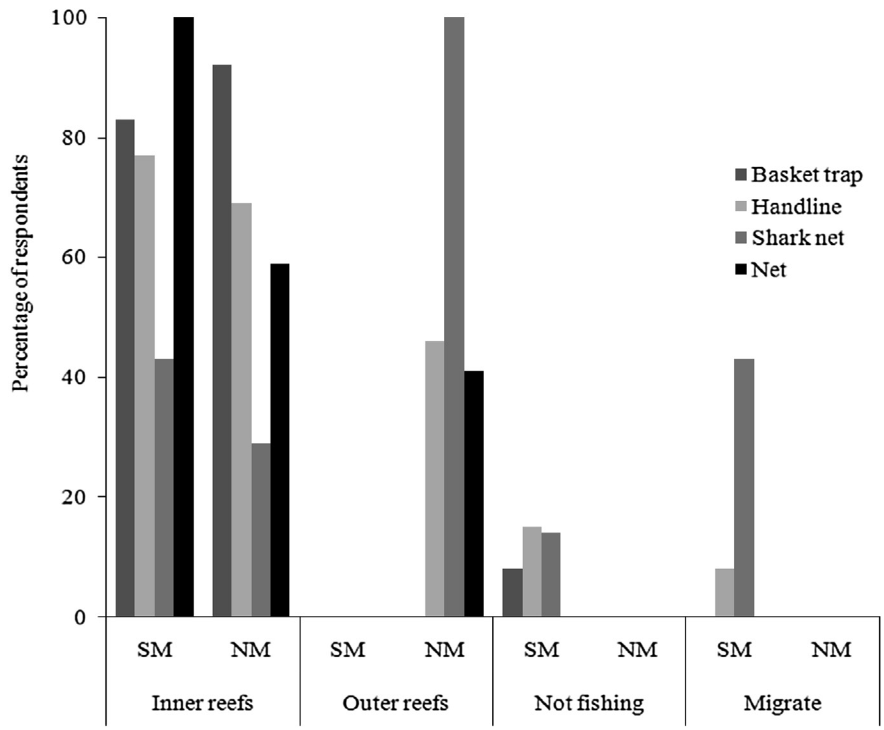

Fig. 2. Fishers' responses (%) to the question: "Where do you fish?" (SM = southeast monsoon; NM = northeast monsoon) according to fishing gear types. Inner and outer reefs refer to areas inside Chole Bay and Open Ocean outside Kinasi Pasi respectively (See Fig. 1).

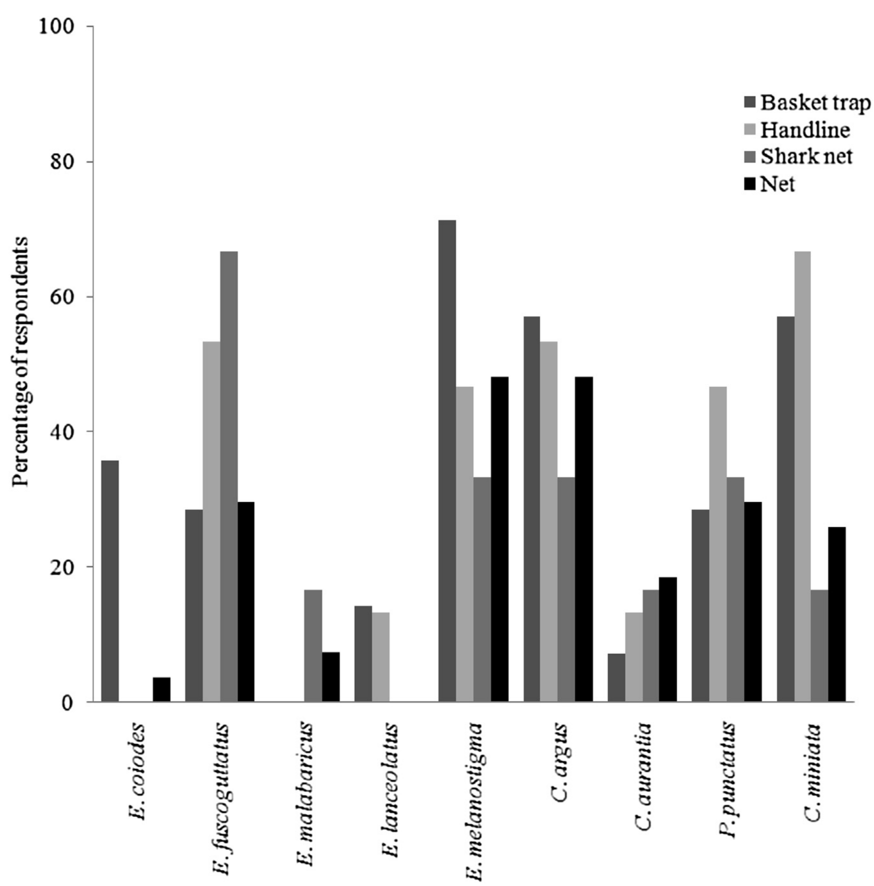

Fig. 3. Fishers' responses (%) to the question "What are the most common grouper species caught?", according to type of fishing gear.

mostly in inner reefs. Overall, a slight majority (54%, n = 61) of fishers stated that groupers are caught mainly in outer reefs, 38% (n = 61) said inner reefs, and 8% (n = 61) had no knowledge about grouper catches. Catch data shown in Fig. 4 indicates no significant differences ($F = 1.06$, $df = 1$, $p = 0.304$) in grouper catch biomass per capita between inner reefs (6.0 ± 5.035 kg^1 $fisher^{-1}$ day^{-1}, n = 207) and outer reefs (6.9 ± 7.4 kg^1 $fisher^{-1}$ day^{-1}, n = 44). However, catch data about shark net fishing is lacking because fishers using this type of gear sell their catch far from village landing sites.

3.2.3. *Seasonal occurrences of groupers*

Individual fishers were asked the question: "If you look at your fishing activities, there must be a season where you catch a lot of groupers – can you share your experience about that?" According to the fishers interviewed, there is no particular seasonal occurrence because groupers are naturally less abundant in the sea. As is evident in Fig. 5, the responses from fishers indicate that groupers in the waters of Mafia Island do not appear to have a particular period of activity which is known to fishers. Moreover, the overall distribution of responses is consistent with catch data collected for the MIMP monitoring program, which shows no significant seasonal differences ($F = 0.05$, $df = 2$, $p = 0.950$) in grouper catch throughout the sampling period (Fig. 6).

3.3. *Biology and ecology of groupers*

3.3.1. *Folk taxonomy of grouper species*

The folk taxa observed in this study are polytypic, with the same name being used to refer to more than one species (Table 6). This is more evident in species of the genera *Epinephelus, Cephalopholis* and *Plectropomus*. For example, the folk name *Mjombo* refers to *Plectropomus* and *Epinephelus* species; *Kiboe* refers to *Cephalopholis* and *Epinephelus*.

Interviews with fishers revealed that folk taxa of groupers are distinguished on the basis of morphological and ecological characters and relations. The most commonly used characters to name the different species of groupers are color and the presence or absence of dots on the skin, for example: *Chewa Mweupe* (white grouper) to refer to the potato grouper, and *Chewa Njano* (yellow grouper) to refer to the Saddleback coral groupers. Other identifying characters are related to body size, structure of the mouth, appearance of the eyes and shape of head, the taste of the flesh, habitat, depth, the environment where they are found, and the social value of a species. Examples of these are *Kichwa Kirefu* (long head) to refer to the humpback grouper, and *Chewa Mwamba* (rocky/reef grouper) to refer to the black-tip grouper.

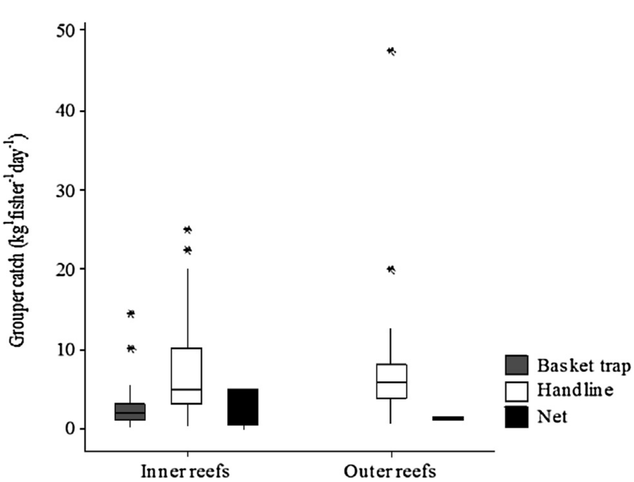

Fig. 4. Boxplots for grouper catches (kg^1 $fisher^{-1}$ day^{-1}) according to fishing site and fishing gear. Unit effort is one day of work (about 7 h at sea). The size of the box shows data dispersion (interquartile range = IQR). Separate points are values beyond the upper fence.

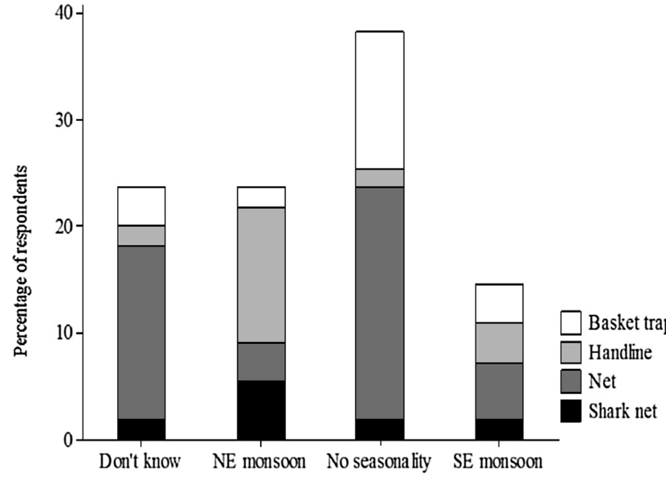

Fig. 5. Fishers' responses to the question: "What is the best season for catching groupers?" (n = 61), according to type of fishing gear.

3.3.2. *Habitat*

Most fishers (97%, n = 16) consider groupers (adult and juveniles) to be associated with a habitat consisting of hard substrata. According to their testimonies, the most common habitats are rocky areas, coral reefs, large rocky caves, crevices, almost submerged tree logs or sunken boats, and seagrass beds. Fishers stated that groupers prefer rocky or coralline habitats because these provide hiding places in caves and crevices, and are suitable for foraging due to the abundance of other fish.

Regarding the vertical distribution along the water column, fishers stated that groupers are found at various depths, ranging from shallow areas to depths of up to 200 m, depending on the nature of the substrate, species preferences and size. Fishers mentioned that particular species that prefer deep water (i.e. more than 20 m) include *Cephalopholis boenak, Plectropomus punctatus, Valiola louti, Epinephelus polyhekadion* and *Cephalopholis aurantia.* Furthermore, fishers observed that although small and juvenile groupers may be found in shallow areas, they move to deeper areas as they grow bigger. Fishers stated that large groupers prefer cool

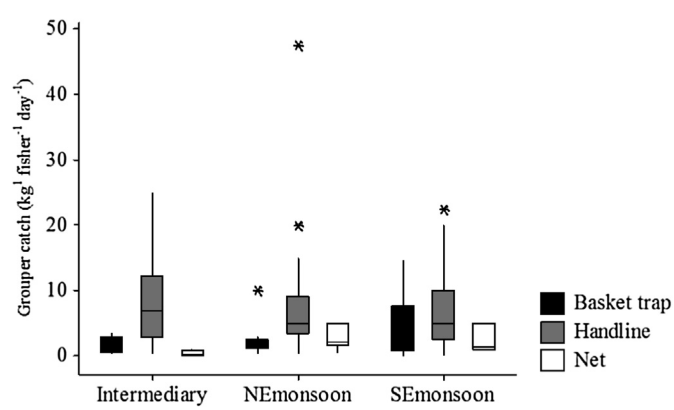

Fig. 6. Boxplots for seasonal (refer to Table 1) grouper catches (kg^{-1} $fisher^{-1}$ day^{-1}) for the period from July 2009 to December 2010, according to fishing gear. Unit effort is one day of work (about 7 h at sea).

Table 6
Fishers' responses to the question: "What are the most common grouper species caught in Mafia waters?

Local name	English name	Scientific name	Frequency mentioned	Comments from fishers with reference to local names
Tone	Blue spotted hind	*Cephalopholis cyanostigma*	1	
	Giant grouper	*Epinephelus lanceolatus*	6	Large, bigger than all groupers. Gear: Hook-and-line, nets (small)
Fungo	Chocolate hind	*Cephalopholis boenak*	2	Produce medicinal oil, Deep water, small size species
	Giant grouper	*Epinephelus lanceolatus*	1	Mouth resembles a shield. Gear: shark net, net
Tungua mbegu	Peacock grouper	*Cephalopholis argus*	1	Gear: Basket traps, Hook-and-line, nets, longlines
	Brown-marbled grouper	*Epinephelus fuscoguttatus*	1	
Kikoko	One-blotch grouper	*Epinephelus melanostigma*	1	Found in shallow areas. Gear: Basket traps but sometimes penetrate out, caught mostly by nets
Ukuti	Slender grouper	*Anyperodon leucogrammicus*	1	
Kanga	Greasy grouper	*Epinephelus tauvina*	1	
Tumbo	Giant grouper	*Epinephelus lanceolatus*	1	Gear: Hook-and-line
Mjombo	Marbled coralgrouper	*Plectropomus punctatus*	12	Reddish, deep reef species, not many in shallow areas
		Plectropomus sp	2	even small ones, a lot of muscles.
	Blue spotted hind	*Cephalopholis cyanostigma*	1	Gear: basket traps (70 cm) but they are rare, Hook-and-line, shark net, nets (100 cm)
		Epinephelus malabaricus	2	
	Giant grouper	*Epinephelus lanceolatus*	1	
Jogoo	Lyretail grouper	*Variola louti*	1	
Kiboe	Blacktip grouper	*Epinephelus fasciatus*	2	Small sized groupers, Reddish in color found in rocky areas.
		Cephalopholis sp	1	Gear: basket traps, Hook-and-line, nets, harpoon
		Epinephelus sp	1	
	Peacock grouper	*Cephalopholis argus*	2	
	One-blotch grouper	*Epinephelus melanostigma*	2	
	Coral hind	*Cephalopholis miniata*	2	
		Epinephelus coioides	1	
Sahale	Red mouth grouper	*Aethaloperca rogaa*	5	Gear: Hook-and-line, shark net
	Brown-marbled grouper	*Epinephelus fuscoguttatus*	1	Gear: nets (80 cm)
Fakudu		*Plectropomus* sp	4	Small in size; resemble *Cephalopholis argus*. Gear: Hook-and-line
Mtangaa	Lyretail grouper	*Variola louti*	8	Reddish, deep water. Gear: Hook-and-line, shark net
	Coral hind	*Cephalopholis miniata*	4	Found in rocky areas, depth between 6 and 20 m, large caves, it is a slick fish. It gazes at divers; Gear: basket traps, Hook-and-line, shark net, nets,
Chewa mweupe	Potato grouper	*Epinephelus tukula*	1	Gear: Hook-and-line
Utati	Brown-marbled grouper	*Epinephelus fuscoguttatus*	1	Have black dots. Gear: Hook-and-line
	One-blotch grouper	*Epinephelus melanostigma*	1	Gear: nets
Madoto		*Cephalopholis* sp	2	Black. Gear: shark net
	White-blotched grouper	*Epinephelus multinotatus*	1	Have very wide mouth
Chewa tili (chechipanda)	Lyretail grouper	*Variola louti*	3	
Chewa kokwe	Blacktip grouper	*Epinephelus fasciatus*	2	Small in size, do not grow big. Gear: nets
Chewa vihobo	Marbled grouper	*Epinephelus polyphekadion*	1	Deep water from 100 m
Kokole	Brown-marbled grouper	*Epinephelus fuscoguttatus*	1	
Sambaro	Chocolate hind	*Cephalopholis boenak*	1	
Fahari	Peacock grouper	*Cephalopholis argus*	1	They are many and don't grow big. Gear: rarely caught by hook and line, nets (juveniles)
Yaya		*Epinephelus* sp	2	Small size with black dots
Kichwa kirefu	Humpback grouper	*Cromileptes altivelis*	2	
Chewa kawaida	Brown-marbled grouper	*Epinephelus fuscoguttatus*	5	Black dots, lives in caves, depth from 6 m to deeper depth, not easy to enter basket traps, bigger ones (>70 cm) found in deep reefs. Gear: Hook-and-line, nets (small)
	One-blotch grouper	*Epinephelus melanostigma*	1	Don't grow big, they are abundant. Gear: Hook-and-line
Chewa njano	Saddleback coralgrouper	*Plectropomus laevis*	1	Have yellow parts in its body
Mjombo mweusi	Giant grouper	*Epinephelus lanceolatus*	2	
Chewa mwamba	Blacktip grouper	*Epinephelus fasciatus*	1	
Chewa mwekundu	Coral hind	*Cephalopholis miniata*	1	Gear: Hook-and-line, shark net, nets (small)
		Plectropomus sp	1	
Chewa mweusi	Brown-marbled grouper	*Epinephelus fuscoguttatus*	2	Gear: basket traps, harpoon, Hook-and-line, nets (juveniles of 30 cm)
	One-blotch grouper	*Epinephelus melanostigma*	2	Found in shallow rocky areas, they are small in size, do not grow big (30 cm). Gear: basket traps,
	Peacock grouper	*Cephalopholis argus*	1	
Chewa pango		*Cephalopholis* sp	1	
Chewa choroko	Peacock grouper	*Cephalopholis argus*	1	Gear: Hook-and-line
Boya	Blue spotted hind	*Cephalopholis cyanostigma*	1	
Chewa kerea	Golden hind	*Cephalopholis aurantia*	10	Deep water species found in caves. Gear: Basket traps, Hook-and-line, shark net

and quiet areas.

3.3.3. Feeding habits

Fishers affirmed that groupers are voracious feeders. They associate grouper feeding preferences with the fishing bait used in handline fishing. Fishers stated that the food items preferred by groupers include fish (snubnose emperor, blue and gold fusilier, Indian mackerel, and filleted groupers), squid, octopus, moray eel, crab, lobster, sardine, soft rocks and sand. Basket-trap fishers stated that groupers do not eat seaweed if this is used as bait in basket traps; instead they may pursue other fish which have entered the trap. When diving to set traps, fishers have observed that groupers hide in caves and crevices to ambush other fish, and they are guarded by moray eels. Fishers' were also asked about predators for groupers. The main predators mentioned were large fish such as sharks, barracuda and moray eels. However, fishers said that large groupers are rarely attacked. Cannibalism was also reported, whereby large groupers eat small groupers.

3.3.4. Reproduction

Asked about the timing of spawning, the majority (75%, $n = 16$) of fishers responded that they have no knowledge about spawning. Those who responded to the question stated that groupers spawn during the cold season between April and July; others said that they spawn during the northeast monsoon and that fingerlings are seen during the southeast monsoon. Responding to the question: “Are there male and female groupers?”, the majority of informants stated that they cannot differentiate male from female groupers. Two fishers said that there are no male and female groupers because they do not mate; one fisher differentiated females and males based on the shape of head, mouth and anal pole, as illustrated by the following quotation: “Female groupers have wider mouth and head as well as large genital orifice while male groupers have narrow genital orifice, elongated pointed mouth and head … .”

3.3.5. Behavior

Key informants were asked whether groupers aggregate at specific times of the year and at specific sites. All of them responded that groupers do not aggregate in large numbers – they may be found in small groups of 2–5 individuals or alone in a cave, or sometimes in a group of 10 individuals on the outer reef. However, no one could provide details of aggregations, nor recall in which month/s these may occur. In relation to homing behavior, fishers said that groupers perform small-scale movements in search of food, and they are able to find their way back to their home site without any problem.

Responding to a question about the threats facing groupers, all informants stated that dead groupers are frequently found floating on the outer reef during the period between September and January. One cause cited by these informants was the large amount of fat tissue found in the viscera. One fisher compared this situation to high blood pressure in human beings that may cause cardiac arrest. A second cause was described as increased seawater temperature causing the fish to suffocate, so that their stomachs inflate and they float to the surface. Other threats to groupers mentioned by fishers include physical injuries by sharks or barracuda leaving them with sores, sickness and fever, which causes them to become thin and weak; as well as organisms clinging to their nostrils.

4. Discussion

The current research demonstrates how fishers' TEK complements CSK in fisheries science and management. Although the use of TEK is attracting more attention globally, in that it can provide valuable information for an ecosystem approach to the management of small-scale fisheries, how it can be used to best advantage at local level is still debated. We analyzed fishers' TEK and compared their interpretations with available documented CSK from Mafia and other areas, in order to elucidate complementarity. Three outcomes arising from this comparison are elaborated in Table 7 (see column 4). The first outcome is ‘agreement’: TEK and CSK are consistent or where TEK adds new knowledge that complements or extends existing CSK about groupers. The second outcome is ‘disagreement’: TEK and documented CSK are inconsistent, thereby raising interesting questions deserving further investigation. The third outcome is ‘no knowledge’: fishers' have no TEK on the ecology and biology of groupers.

4.1. Agreement between fishers' TEK and CSK

Comparing TEK and CSK reveals much about what grouper species are utilized, and where and when they are caught. This information is of considerable value to fisheries managers and policy makers. For example, most of the resource-use patterns and effort exerted revealed in the qualitative data collected about groupers in Mafia is consistent with that reported by Fischer et al. (1984). However, information on specific grouper species caught using ‘nets’ (as defined in this study) is lacking. In this case, fishers' TEK is the only available source of information to complement conventional science data. Furthermore, there was no agreement among fishers or with catch data about fishing locations for groupers. Responses from fishers were mixed on this topic, indicating that knowledge of fishing locations is linked to type of fishing gear used and where it is deployed. Analysis of catch data shows that inner reefs are visited more frequently than outer reefs, while outer reefs located outside the reserve boundary are richer in groupers' biomass. Thus, both TEK and CSK data on fishing grounds provides detailed information about regions important for catching groupers and where possible monitoring efforts could focus on. Furthermore, TEK on catching groupers corresponds to catch data, thereby placing more confidence on the absence of seasonality in catching groupers. The observed seasonal differences in landings of *Epinephelus malabaricus* reported by Gaspare and Bryceson (2013) may be due to variations in fishing effort caused by changes in sea conditions which limit access to fishing grounds. Thus, the evidence suggests that TEK could reliably be used by scientists and managers to document fish species of economic importance at the local scale.

We note that fishers’ naming of groupers is similar to that reported by Begossi and Silvano (2008) in Brazil. They report that fishers often referred to 'garoupa' as more than one species of *genus Epinephelus*. Further, interviews with fishers in this study revealed that folk taxa of groupers are distinguished on the basis of morphological and ecological characteristics and relations, as observed by Caló et al. (2009) for snapper fish in Ilhéus, Bahia, Brazil. However, a possible problem with color identification is that it may be valid for young groupers, but as the years progress, it may lead to double counting (Polovina and Ralston, 1987). Therefore, the corroboration of information mentioned by fishers and data from conventional science surveys offers confidence that biological patterns for groupers observed in this study would also be applicable elsewhere.

The identification made by fishers in this study is a useful contribution towards characterizing groupers in Tanzania (see Bianchi, 1985). The number and names of grouper species mentioned by fishers show that groupers form part of their daily life, as a source of both food and income. Moreover, some species of groupers mentioned by fishers are not reported by Bianchi (1985), but are reported by Heemstra and Randall (1993). The fact that fishers identified more than double the number of grouper species reported by Bianchi (1985) suggests that her survey might not have been extensive enough to document all grouper species occurring in Mafia. Moreover, more extensive sampling is required to establish a conclusive database of groupers occurring in Mafia. This information could form the basis for collaboration between fishers, scientist and managers in fisheries development and management. In the future, researchers could apply more sophisticated technology such as genetic techniques to identify and classify groupers, as well as underwater video mapping to study ecological traits of different grouper species.

Due to the scarcity of information on grouper habitat preferences and diet, as well as their high vulnerability to fishing, it is important to investigate the ecological traits of groupers. Discussions with fishers demonstrated that local accounts of grouper habitat preferences correspond closely to what is reported by conventional science. Some studies indicate that groupers are associated with hard substrata due to refugia, and the availability of prey, since most groupers are ambush predators (Heemstra and Randall, 1993). Moreover, groupers occupy various depths from the shallows to deeper water. According to Heemstra and Randall (1993), depths vary widely for *Cephalopholis boenak* (1–64 m), *Plectropomus punctatus* (3–62 m), *Valiola louti* (3–250 m), and *Epinephelus polyhekadion* (1–46 m), while *Cephalopholis aurantia* (100–250 m) is a deepwater species. Scientific studies show that large fish prefer deeper areas because oxygen levels are more favorable (Pauly, 2010). The fishers in this study, on the contrary, did not associate oxygen needs of large groupers with a preference for deeper areas; such information is perhaps less useful in their daily catch when compared to feeding habits. Further discussion with fishers revealed several threats facing groupers that are of concern to fisheries management. These include parasites (Thompson and Munro, 1978) and death by unknown causes. Similar observations by fishers about deaths of groupers are reported by Gerhardinger et al. (2006) on *Epinephelus itajara* in southern Brazil. Although fishers viewed death of groupers as a common event, the phenomenon is yet not documented by conventional science in the western Indian Ocean.

Fishers' TEK in Mafia has extended current knowledge about grouper feeding habits documented in the literature and pertaining to other areas. This is due to a lack of previous studies on the ecology of groupers in Mafia. Fishers described groupers as voracious feeders, preferring to eat crustaceans, cephalopods and finfish. The items that constitute the diet of groupers reported by fishers agree with data from the biological literature on grouper diets (Randall and Brock, 1960; Thompson and Munro, 1978; Randall, 1987; Begossi et al., 2012). These congruent responses represent a shared understanding by CSK and TEK of what groupers eat, which is the most important information needed for capturing fish and assessing ecological processes (Silvano and Begossi, 2012). However, soft rocks and sand as a constituent food item for groupers, and their preference for specific fish species, are new observations that merit further investigation and offer the chance of potential new discoveries. Considering this finding, we argue that more research is needed in order to draw conclusions about feeding habits that are not biased towards one knowledge system.

Consistent with findings from this study, Silvano and Begossi (2012) assert that information from fishers may help scientists and managers to understand and assess complex ecological processes along the food chain. For example, in this study fishers mentioned that predators for groupers as sharks, barracuda, and

Table 7
Assessment of the complementarity of fishers' traditional ecological knowledge (TEK) and conventional scientific knowledge (CSK).

Topic	Traditional ecological knowledge (TEK)	Conventional scientific knowledge (CSK)	Outcomes in comparing TEK and CSK
Fishing methods and types of gear	Fishers provided information about different types of gear used to catch groupers. The data also shows specific grouper species caught and various tactics used by fishers in order to maximize daily catch. These variables are significant for the management of fisheries.	Lack of data from Mafia highlights the need to integrate TEK and CSK for more complete information. However, data is available at regional scale (Fischer et al., 1984).	Agreement
Fishing locations	Information is available from fishers in the form of catch data on exactly where groupers are mostly caught.	Lack of data highlights the need for integrated research such as the use of GIS to map fishing zones	No data from CSK
Seasonality	Information from fishers indicates no particular seasons for catching groupers. Catch is influenced by weather conditions, fishing gear and vessel types.	Catch data indicated no seasonal differences in grouper landings.	Agreement
Names of groupers	Local names provide basis for further scientific investigation of grouper species occurring in Mafia waters.	Few species are reported for Mafia (Bianchi, 1985); however, CSK provide large spatial scale accounts for grouper species (Craig et al., 2011).	Agreement
Habitat	Information on grouper habitat was collected at local level, where no study had been conducted before. The congruence between CSK and TEK provides greater confidence in both knowledge sources.	Grouper habitat is documented internationally such that it provides greater confidence in the extrapolating CSK from other areas (Heemstra and Randall, 1993) to Mafia.	Agreement
Feeding habits	TEK validated the use of CSK from other areas and provided additional information on feeding habits and predation.	There are no local studies on feeding habits of groupers. CSK from other areas (Randall, 1987) agrees with TEK.	Agreement
Spawning season	Low level of TEK and some incongruence in knowledge highlights the need for more research on the spawning season.	Low level of knowledge from the same geographical area (Robinson et al., 2007; Gaspare and Bryceson, 2013) highlights the need for more research on the spawning season.	No knowledge
Sex differentiation	Very low level of knowledge highlights the need for engagement and collaboration in researching TEK and CSK.	High level of knowledge, documented for grouper species from other areas (Sadovy and Colin, 1995).	No knowledge
Spawning aggregation	Information from fishers in Mafia contradicts TEK available from other areas, highlighting the need for more research.	Lack of CSK about spawning aggregation in Mafia, although spawning aggregation is documented internationally (Zeller, 1998; Robinson et al., 2014).	Disagreement
Fish condition	Information is available about environmental threats facing groupers.	No study has documented diseases, parasites and other environmental threats to wild groupers in Mafia. Information in available from elsewhere (Thompson and Munro, 1978).	Agreement

moray eels – and large groupers eat small and juvenile groupers. This phenomenon of old members of a population eating young ones is termed "intercohort cannibalism" (Smith and Reay, 1991). In cultured fish populations, knowledge of cannibalism is important, and intercohort cannibalism can be easily controlled by size separation. In wild stock, cannibalism has a regulatory effect on population abundance and contributes to natural mortality (Ricker, 1954). Thus, managers and scientists need to be aware of cannibalism when proposing regulations for controlling predators in the hope of improving stocks of prey. However, both fishers and conventional scientists lack knowledge about genetic relationships between cannibal and prey (Smith and Reay, 1991). This topic is essential for management and aquaculture development and deserves further investigation. Furthermore, fishers reported that moray eels act as guards for groupers, but scientific studies have recorded that groupers and moray eels form coordinated hunting whereby groupers catch fish that are chased by eels into coral reef areas (Diamant and Shpigel, 1985). This difference in knowledge may be due to the failure of fishers to understand or interpret specific ecological processes. There is thus a need for participatory research on such phenomena, although that may require considerable fieldwork and expertise.

4.2. Disagreement between TEK and biological data

Some aspects studied revealed inconsistencies between fishers' TEK and CSK, thereby raising questions deserving further investigation. Incongruence was found between fishers' knowledge and documented biological data concerning spawning aggregations of groupers. Studies in the Caribbean, Bahamas, Seychelles and Kenya have shown that groupers aggregate to spawn at specific sites, and that those sites are known to local fishers (Domeier and Colin, 1997; Robinson et al., 2004; Samoilys et al., 2006). Conversely, the majority of fishers interviewed in Mafia claimed that groupers do not aggregate at all. Based on these responses, it appears that fishers are not aware of the phenomenon, perhaps due to the inaccessibility of offshore sites where groupers are likely to aggregate for spawning. Therefore, the question as to whether or not spawning aggregations occur in Mafia remains unsettled and deserves further investigation.

4.3. Aspects in which fishers lack knowledge

The majority of fishers at Mafia Island appear to have no knowledge on the reproductive aspects of groupers. This is evident from responses we received about the spawning season and sex differentiation. The responses revealed a fragmented understanding of grouper spawning, indicating that local knowledge of grouper reproductive behavior is poor. A study by Gaspare and Bryceson (2013) found that *E. malabaricus* spawn from September to January. Similarly, Nzioka (1979) studied spawning seasons of East African reef fishes and found that the spawning seasons are from October to January. Concerning sex differentiation, knowledge of sexual dimorphism in groupers is not common; studies have shown that many species of groupers begin life as either female or male and change sex later (Sadovy and Colin, 1995). Fishers were not aware of the reproductive strategy of groupers, and hence they appreciated exchanging such information with us when working together during fieldwork. Silvano and Begossi (2010) assert that knowledge of fishers is closely linked to fishing practices. The observed lack of knowledge of grouper reproduction could be related to limited capacity to catch mature groupers, or perhaps the fish are sold ungutted without fishers having the chance to see the gonads. It may be that fishers have no need to know the details of reproduction in groupers, because they do not target spawning aggregations. The most important aspects for fishers to be aware of are the feeding behavior and habitat of groupers, so that they can select bait and fishing grounds to target a catch that will support their daily needs.

4.4. Contributions to the management of fisheries

Fisheries management in Tanzania is usually based on top-down regulations such as the establishment of closed fishing areas, gear restrictions and licenses. These regulations may be altogether uninformed, or rely on scarce information derived solely from CSK. This situation raises serious conflict between fishers and managers. We argue that fishers' TEK is a source of meaningful and relevant data that could inform the conservation and management of fisheries (Salas and Gaertner, 2004). Our results demonstrate that fishing patterns are based on traditional knowledge which requires an understanding of ecological processes. For example, fishers' knowledge of feeding habits helps them to understand how the loss of groupers (as a consequence of overfishing or environmental threats) or increased abundance of predators' could negatively affect coral reef fish communities. Likewise, fishers' observations help to interpret catch data recorded at landing sites. Therefore, fishers' TEK about the ecology and biology of economically important fish species could be a starting point to enhance dialogue among fishers, scientists and managers, thus promoting mutual understanding.

The contemporary utilization of groupers is affected by complex interactions between traditional fishing practices, natural factors related to monsoon winds, and knowledge of the biology and ecology of groupers. Further, our analysis indicates that fishing activities are influenced by fishers' knowledge of habitats and the availability of fish. Fishers use a diversity of fishing gear in order to cope with perturbations and reduce risks associated with limited fishing technology. We found no specialization tendencies in terms of fishers targeting groupers, implying that fishing efforts are distributed to other species of economic value, thus putting less pressure on grouper populations. In such a context, the integration of fishers' knowledge is crucial for the effective management of existing marine protected areas and the establishment of new ones. Such an approach would reduce unnecessary conflicts that arise from top-down management approaches (Aswani and Lauer, 2006).

CSK indicates that the spawning season for groupers is from September to February, a period that coincides with calm sea conditions. This period would be appropriate for managers, scientists and fishers to work together in order to establish a common understanding of the reproductive patterns of groupers, since our results indicate fishers' TEK on this topic is lacking. Furthermore, spawning aggregations of groupers around Mafia are unknown to both fishers and scientists in Tanzania, indicating that the resource may continue to be utilized sustainably. However, it should be clearly noted that this study involved only fishers who live around Mafia Island, while groupers are utilized by fishers from different parts of Tanzania who may have different knowledge. Furthermore, we understand that growing global demands for fish, increases in market prices, and increased ease of capture due to more efficient fishing gear, may all gradually increase the intensity of fishing. We therefore argue that a precautionary approach using the available information from both TEK and CSK will be appropriate in controlling and managing small-scale fisheries.

5. Conclusions

In this study we evaluated the complementarity of fishers' TEK and CSK in the context of small-scale fisheries in order to contribute to knowledge and improve the management of fisheries. Our data analysis focused on fishing practices and examined fishing patterns in relation to fishing gear and vessel types, fishing grounds, and fishing tactics for catching groupers, together with an assessment of catch data. Further, we compared fishers' TEK and CSK on the ecology and biology of groupers. Finally we highlighted the implications of our findings to improve the management of complex small-scale fisheries systems.

Our results indicate that TEK generated some information that confirms scientific data, elicited knowledge that was new to both TEK and CSK, and highlighted some differences between TEK and CSK (e.g. spawning behavior). These discrepancies can be attributed to a number of factors, including observational differences at spatial and temporal scales, as well as methodological differences (e.g. sample size) in gathering data that can generate knowledge of relevance to fisheries management. We therefore conclude that TEK and CSK complement one another, and should be used together, but in full recognition of their limitations.

Notwithstanding that word of caution, this comparison makes three important general contributions to improve the monitoring and management of small-scale fisheries in Tanzania and in other tropical developing countries. First, TEK provides fast and reliable biological data to support conventional management regulations such as closed areas and seasons, size and species restrictions, and gear restrictions. Further, local naming of groupers is of practical use to scientists and managers in gathering information about which species are targeted, or are economically or culturally important (Drew, 2005). Second, traditional fishing methods and technologies used by fishers are predicated on knowledge of fish behavior; this knowledge can be adapted for the use of modern technology. For example, camouflaging traps with dead corals shows the importance of local knowledge about fish habitats and provides an impetus for preserving natural reefs. Third, fisheries managers should consider incorporating traditional management approaches based on natural season closures into fisheries planning, monitoring and enforcement of regulations, under a co-management approach.

We argue that conservation and fisheries management will benefit from this comparison of TEK and CSK, especially in fishing communities where decisions are obscured by uncertainty related to ignoring fishers' knowledge and practices, and a lack of biological and fisheries data. We hope that in addition to improving the overall political and socio-economic aspects of fishing in Mafia, our results will form a basis for establishing collaborative engagements between fishers, conventional scientists and fisheries managers that embrace both TEK and CSK suitable for sustainable fisheries utilization.

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PAPER IV

Effectiveness of Marine Protected Areas on fisheries management: Fishers' opinions in Mafia Island Marine Park, Tanzania

Lydia Gaspare[a, b]

Department of International Environment and Development Studies (Noragric), Norwegian University of Life Sciences, 1432 Aas, Norway.[a]

Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, P.O. Box 60091, Dar es Salaam, Tanzania.[b]

E-mail address: lgaspare@yahoo.co.uk
Tel: 255222650011, Fax: 255222410480, Mobile: +255766302961

Abstract

How fishers perceive the outcomes of Marine Protected Areas (MPAs) is fundamental in evaluating the effectiveness of management practices. This study examined the perceptions of fishers on the outcomes of the multi-use Mafia Island Marine Park (MIMP) including core zones. The results of semi-structured interviews with fishers randomly selected from two communities indicate that perceptions are influenced by area of residence, age and fishing gear in use. Fishers were positive about coastal habitat conditions and the elimination of dynamite, poison and beach seine fishing; and they showed a high level of understanding about MIMP regulations. Perceptions about the effects of the MPA on fishers' own activities, fisheries in general, and the violation of MPA regulations differed with age, gear used and among fishers from the two villages. Respondents who reported being affected by the MIMP were more likely to be those from the community with high reliance on fisheries resources, young fishers, and those using nets and motorized boats. Perceptions about fish catch trends, involvement in planning, enforcement of regulations, and level of conflict did not differ among communities and gear users, but deviated negatively from MIMP goals. Thus, efforts focusing on improving access to sustainable income sources, promoting sustainable fishing gear and developing legal frameworks that support local knowledge and practices may enhance the effectiveness of fisheries management.

Keywords: fishery closure, fisheries management, small-scale fisheries, fishers' perceptions, Marine Protected Areas

1. Introduction

Marine Protected Areas (MPAs) have received much attention as an alternative approach to conventional fisheries management; yet their effectiveness in the tropical developing world is sparsely documented. Evaluation of the performance of MPAs as a fisheries management tool is essential since their failure may lead to a loss of biodiversity and habitats and threaten traditional livelihoods (Jones, Qiu and De Santo 2013; Ruiz-Mallén and Corbera 2013). In this scenario, effectiveness refers to the degree to which management actions meet stated goals and objectives and ultimately improve the status of ecological and social systems (Hockings, Stolton and Dudley 2000; Pomeroy et al. 2005).

A study conducted by Halpern and Warner (2002) indicates that MPAs are successful in the management of fisheries and the preservation of biodiversity in many parts of the world. Likewise, McClanahan and Mangi (2000) and Russ et al. (2004) assert that MPAs associated with core zones may be beneficial to fisheries as a result of an increase in the biomass and abundance of fish and other spillover effects. However, few studies have empirically assessed the effectiveness of MPAs in managing small-scale fisheries in East Africa (Kamukuru et al. 2004; Muthiga 2009; Machumu and Yakupitiyage 2013). Besides the lack of adequate biological and fisheries data about the performance of MPAs, there is also inadequate data regarding fishers' opinions on the management outcomes of MPAs (Pita et al. 2011). According to Leleu et al. (2012) and Velez, Adlerstein and Wondolleck (2014), fishers' perceptions are an essential indicator of the social acceptance of MPAs, because they tend to influence their behaviour and decision making. Velez and colleagues assert that "in order to increase the likelihood of NTZ effectiveness, it is necessary to understand fishers' interests and concerns, analyze the impact of core zones on their livelihoods and involve them actively in the decision-making process" (Velez et al. 2014, 172). In other words, MPAs are more likely to succeed in their social and ecological purposes if fishers perceive the benefits (such as increases in their catch and providing nursery grounds for fish), and there is mutual understanding between fishers and managers (Alcala and Russ 2006; Klein et al. 2008; Leleu et al. 2012). Furthermore, understanding the extent and causes of variability of fishers' perceptions is essential in order for MPAs to produce optimal outcomes as a fisheries management tool. If MPAs have low levels of support from fishers, they may become ineffective in achieving their goals (Christie 2004; Dimech et al. 2009; Charles and Wilson 2009).

In Tanzania, MPAs were established for the purpose of, inter alia: (1) the conservation of biodiversity and ecosystem processes; (2) the promotion of sustainable resource use and rehabilitation of damaged ecosystems; and (3) the involvement of local residents in the development and management of the park, ensuring that they have priority access to resources and economic opportunities (URT 2000). The intention was to benefit local communities while maintaining sustainable resource utilization, by combining the interests of various resource users, and responding to local population increases and the pressure of outside users (Hooper 1996). Management models currently used on Mafia Island include closed areas, gear restrictions and limiting the number of fishers under a co-management philosophy (Horrill and Ngoile 1992; Francis, Nilsson and Waruinge 2002). However, studies documenting the human dimensions of MPAs in Tanzania found that fisheries closures have frequently been disputed by local communities, thereby aggravating conflicts between fishers and managers (Mwaipopo 2008; McClanahan et al. 2009; Benjamisen and Bryceson 2012). Hamilton (2012) and Kincaid, Rose and Mahudi (2014) attribute the lack of social support for MPAs to the level of fishers' involvement, proximity to fishing grounds, restrictions on fishing gear types and fishing management regimes.

This study aimed to test the value of fishers' perceptions and opinions as indicators of MPA effectiveness in managing small-scale fisheries in Mafia Island, Tanzania. To meet this aim, we posed two specific research questions. Firstly, what are the factors that affect fishers' support for and opinions on MPAs? Secondly, how fishers' views concur with, or deviate from reported MIMP achievements? The study offers some understanding of the level of MPA effectiveness within the local context appropriate for Mafia small-scale fisheries; it may also be relevant to other areas that are implementing integrated conservation and fisheries policies.

2. Materials and Methods

2.1 Study area

Mafia Island and its small islets are located approximately 120 km southeast of Dar es Salaam and 21 km offshore from the eastern extent of the Rufiji Delta. The island is about 48 km long and 17 km wide at its widest point, and covers a total area of 413 km^2. The 2012 census reported a population of 46,438 (www.nbs.go.tz/). The monsoon winds, and the north flowing East African Equatorial Current influence the climate of the area. The area is characterized by dry and rainy seasons and is warm and humid throughout the year. The southeast monsoon predominates from April to August with strong winds, while intermediate easterly winds blow from September to October. The northeast monsoon predominates from November to March, with relatively gentle winds blowing in the opposite direction. The sea surface temperature ranges from 25 ^{o}C to 31 ^{o}C, with June to August being a cool and dry season. The period from March to May is characterized by long rains, while scattered showers fall in August and September, and short rains fall from October to December. The study was conducted in the southern part of the island which is under Mafia Island Marine Park (MIMP) conservation measures (Fig. 1).

MIMP is a multiple-use marine and land facility where human settlements are allowed to remain within the park boundaries; over 50 percent of the population of Mafia Island lives within the MPA boundaries. In order to integrate conflicting interests among user groups, a zoning plan was adopted within the MPA. The plan designates three zones: core zones, specified-use zones and general-use zones. The different zones have particular regimes of protection and permitted activities (Table 1). In the core zone, no form of exploitation is allowed; in the specified-use zone, specific forms of exploitation are allowed; and in the general-use zone all legal forms of exploitation are allowed. Outside the MPA boundaries, general national fisheries regulations apply.

2.2 Data collection

Fieldwork was conducted between January and March 2011 as part of a wider study examining linkages between ecological and social systems for sustainable small-scale fisheries. The primary data collection methods used were in-depth interviews with key informants at various organization levels, semi-structured interviews with fishers, focus group discussions, field observations, and informal conversations. Secondary data were obtained by analyzing various publications related to fisheries management and marine parks in Tanzania, obtained from the

World Wide Fund for Nature office in Mafia Island, the library at the MIMP headquarters and web-based searches. The publications included scientific publications, local newspaper cuttings, minutes of meetings, Acts and regulations, policy statements and MIMP annual reports. Field observations and field notes were used to triangulate information and enhance the reliability of data obtained from interviews.

Semi-structured interview questions were designed to investigate the opinions of fishers towards various aspects of MPAs and to assess their support for MPAs. Questions were separated into two sections: The first part focused on characteristics of a fisher (such as their age, fishing experience, area of residence, fishing methods, etc.) and the second part sought fishers' opinions about the effects of MPAs and their involvement in the management process. The questions were designed to allow a comparison of a range of opinions (data from the second part), and to investigate whether fishers' characteristics collected in the first part (explanatory variables) influence their opinions.

Semi-structured interviews were carried out by one interviewer (the author) and conducted in Kiswahili, the language spoken by all fishers. A total of 61 fishers were interviewed in two communities: 33 from Kiegeani and 28 from Juani. They were all small-scale fishers, some fishing alone, and others in crews (one fisher owning a boat used by other fishers in the crew). They were all males ranging in age from 24 to 80 years (average 45 years), with fishing experience ranging from 2 to 70 years (average 26 years). They were approached randomly and each interview lasted for 50-60 minutes.

Twelve additional interviews were carried out with key informants, each lasting between 50 minutes and two hours. Interviewees included village chairpersons, MIMP officials, local government officials and fisheries extension officers. Focus group discussions were conducted with migrant fishers in Juani and Kiegeani, leaders of fishing groups in Juani, and village liaison committee members in both communities. All interviews were audio recorded (with permission from the participants) and transcribed on-site for easy consultation in case of any inconsistencies and to check the accuracy and completeness of the transcriptions.

2.3 Data analysis

Before analysis, all interview data were entered into a spreadsheet using Microsoft Excel and copied into a statistical software package (IBM SPSS version 20) for analysis. In order to allow an unrestricted range of answers, responses from fishers were grouped after questioning, rather than providing categories for consideration by the respondents. Answers were categorized as Satisfied, Neutral, or Dissatisfied; Yes or No; and Positive, Don't know, or Negative (Appendix 1). Fishing gear was reduced to two categories: mobile gear (net fishing including shark nets) and static gear (hook-and-line, basket traps, harpoon). Qualitative responses from open-ended questions were explored, captured in quotation form, and displayed in relevant categories in tabular format.

To test for significance between variables, Chi-square tests for independence and multinomial logistic regression were used and significance was determined at $\alpha = 0.05$. Other studies (Blyth et al. 2002; Crona 2006; Abernethy et al. 2007; McClanahan et al. 2009) identified factors which influence fishers' perceptions and acceptance of MPAs, namely age, fishing experience, fishing gear operated, vessel type, perceptions of catch trends and access to other sources of income. These factors were tested against fishers' responses, in order to investigate any influences on fishers' perceptions (H_0 = *Fishers' characteristics have no influence on their perceptions of MPA outcomes).* Relationships were also explored between fishers' area of residence, gear type, fishing experience, vessel types and source of income, using the same methods of analysis. Several questions where used as proxy for fishers' acceptance of MPAs, including: Fishers' opinions on the effects of MPAs on fisheries, and effects on their own fishing activity. Fishers' perceptions of their level of involvement in MPA management were tested against responses to proxy questions of acceptance, in order to investigate whether management input has influenced fishers' support of the MPA (Appendix 2). Finally all responses to all questions were assessed qualitatively against published information about the park (for the year 2011), in order to evaluate the effectiveness of an MPA as an effective approach to fisheries management.

3. Results

3.1 Perceptions of biophysical indicators

3.1.1 Changes in number of fishers

Respondents were asked to assess the status of fishing pressure now and before the inception of the MPA and the majority (88 %, n = 61) said that the number of fishers has increased. The increase was associated with, among other reasons, lack of alternative employment, population increase, and lack of opportunities for post-primary education (Table 2). The MIMP warden-in-charge stated that the number of fishers inside the park is increasing because of increased market prices, demands from the processing plant for more fish, and increased fish abundance due to protection. Responding to a question on how the MIMP is dealing with the increased influx of non-resident fishers (NRFs), officials reported that a number of measures are being taken to regulate the number of fishers. These include user permits and user fees, restricting fish traders from outside Mafia, and working with fisheries units and volunteer informers to minimize the influx of external fishers. NRFs are also required to obtain a formal letter of identification from a village liaison committee (VLC) before the MIMP will grant a fishing permit.

The management of NRFs is affected by a number of challenges including the following: kinship as a result of marriage; nepotism; petty corruption; insufficient funds to patrol all areas at once; oceanographic characteristics related to monsoon winds; ineffective issuing of identity documents to MIMP residents in order to exclude outsiders; lack of legal power for the MIMP to arrest violators outside MIMP boundaries; weak enforcement of fisheries regulations outside the park (evidence from recurrences of dynamite fishing practices).

3.1.2 Changes in type of fishing gear

Responding to the question: "Are there changes in types of fishing gear now, compared to before the MPA started?" the majority of fishers (75 %, n = 61) perceived changes in fishing gear type, while 25 % of them said that there are no changes. Identified changes include increased use of pull nets, decreased use of handlines and traps, and discontinuation of dynamite and beach seine fishing. Fishers said these changes were caused by decreasing fish abundance in shallow waters, availability of efficient vessels with outboard engines, MIMP regulations, increase in the number of fishers, and the need to earn cash money. When fishers were asked why they were using pull nets, some said that the gear is efficient in increasing their fish catch and thus their income. Others mentioned issues such as lack of experience with other gear, increased social ties and cooperation among crew members on fishing vessel (In operation, each pull net can employ 5–22 fishers at one time) and lack of alternative fishing gear that they were promised at the time of park inception. Fishers stated that the total catch from set-net fishing is not adequate to sustain their families.

When asked for opinions on the fishing gear exchange program launched by the MIMP to promote environmentally friendly fishing practices and to enable fishers to fish offshore, fishers from the two communities had significantly (χ^2 = 6.212; d.f. = 2; p = 0.037) different views. In Kiegeani and Juani respectively, 25 % and 56 % of fishers were dissatisfied with the programme, while 53 % and 24 % respectively expressed no opinion because they did not receive any fishing gear from the MIMP. According to fishers' testimonies, their sense of dissatisfaction was caused by the MIMP not considering the dynamics of fishing practices, fishers' behaviour and knowledge of fishing, the economic status of the community, and the geographical location of the villages (Table 3).

3.1.3 Condition of coastal habitats and fish catch trends

Fishers were asked if there have been any changes in the condition of coastal habitats (coral reefs, mangrove and seagrass) and fish catch trends since the inception of the MPA. The majority (> 60 %) of fishers in both Kiegeani and Juani perceived that the condition of coastal habitats is now 'good' (Fig. 2). Fishers attributed the improvement in these habitats to prevention by the MIMP of dynamite and small-mesh seine net fishing, coral mining and mangrove cutting.

Conversely, the majority of fishers from both communities reported that their total fish catch has decreased since the establishment of the MPA (Fig. 3) (the influence of fishers' characteristics on this variable was not significant). Long-term fisheries-dependent catch data were not available for comparison. As is evident in Table 4, the majority (63 %, n = 37) of fishers are of the opinion that the declining fish catch trend is due to overutilization of the resource.

Other fishers were of the opinion that the decline has been caused by changes in water temperature that affect the behavior of fish, as noted by one fisher:

> "Before the MPA was established we were catching many fish but nowadays you hardly find a school of fish like we used to see, I am not sure whether they are overfished or are conserved in core zones! But I don't agree that fish are reared in core zones because fish have the tendency to move to different sites. There are changes in weather conditions, water temperature has increased drastically even in period of rains. Fish prefer cold water." (Interview # 52 February 2011)

Fishers also complained that overcapitalized foreign fishing vessels that fish illegally near Mafia reefs are responsible for the depletion of fish stocks. Fishers claimed that large-scale fisheries catch brood stock in deeper areas; hence fewer fish come into shallow areas that are accessible to small-scale fisheries, thus making the sea a 'desert'.

3.1.4 Effects of the MPA on fisheries in general

When asked about effects of the MPA on fisheries in general, fishers from the two communities had significantly (χ^2 = 5.115; d.f. = 1; p = 0.007) different opinions. The subsequent statistical analysis shows that fishers from Juani were more likely to state no benefits (χ^2 = 5.115; d.f. = 1; p

< 0.05). The percentages of fishers who perceived no benefits of core zones to fisheries were 52 % from Kiegeani (n = 33) and 80 % from Juani (n = 28). The reasons for no benefits about core zones are associated with the lack of direct benefits to fisheries (Table 5). Conversely, 48 % of fishers from Kiegeani and 20 % from Juani expressed positive perceptions. These fishers emphasized that core zones are beneficial in terms of conserving fish in order to reproduce to the benefit of fished areas.

3.1.5 Effects of the MPA on fishers' own fishing activities

Fishers were asked about effects of the MPA on their own fishing activities. Statistical analysis shows significant ($\chi^2 = 3.24$; d.f. = 1; $p = 0.023$) differences in answers among fishers from the two communities. Fishers from Kiegeani (56 %) were more likely to perceive positive effects of the MPA than fishers from Juani (31 %). A Chi-square test shows a significant ($\chi^2 = 11.22$; d.f. = 1; $p = 0.002$) association between net fishing with a motorized boat and negative perceptions of MPA effects on fishers' own fishing activities. These fishers reported decreased income from fishing resulting in deprivation (Table 6); increased unemployment; and increased expenses because of the travelling distance to fishing grounds. The perceived effects of the MPA on fishers' own fishing activities are negatively associated with age ($\chi^2 = 4.699$ d.f = 1, $p = 0.036$), as there is a positive association between young fishers (35 years or less) and net fishing ($\chi^2 = 5.043$ df = 1, $p = 0.027$).

3.2 Fishers' perceptions of governance indicators

3.2.1 Involvement in planning and MPA implementation processes

The majority of fishers from Kiegeani (69 %) and Juani (76 %) were dissatisfied with their involvement in the process of establishing the MIMP. According to fishers, the main reason for their negative perceptions was the lack of initial understanding about the planned outcomes of the MPA. Fishers said that they were told only about the benefits and not about any adverse impacts, such as areas being closed for fishing. One fisher said:

> "I was asked by an 'expert' to participate in putting marker buoys to demarcate the now-called 'core zones', but I felt very sad when the buoys were deployed because I realized we were deceived. The expert asked me "is it necessary you should fish?" I replied, it is not necessary but my worry is how will I survive? The expert answered "life will continue and it is not necessary to fish, isn't what you need is money?" We will give you alternative ways of making a living. To my surprise I was provided with fishing nets and a vessel again. This made me to think there was a hidden agenda which we did not realize at the beginning." (Interview # 33 February 2011)

More than half of the fishers interviewed (74 %) stated that the initial agreement was to eliminate dynamite and beach seine fishing, and allow resident fishers to continue fishing. Few fishers said that the MIMP was established in order to regulate and protect fisheries (17 %), or to provide social support to communities (19 %). Fishers who were satisfied with local involvement in planning of the park were also likely to perceive positive effects of the MPA ($\chi^2 = 11.755$; d.f. = 2; $p = 0.003$) on their own fishing activities.

3.2.2 Involvement in enforcement of fisheries regulations

Involvement in enforcement of fisheries regulations was not associated with acceptance of the MPA. Generally, there was no significant difference ($\chi^2 = 0.072$; d.f. = 1; $p = 0.771$) in responses from fishers in the two communities: 55 % of fishers in Kiegeani and 48 % of those in Juani were satisfied with their involvement in enforcement. Positive responses were related to fishers' willingness to inform authorities about illegal fishing, relying on the philosophy that "every person is a soldier"[1], self-enforcement of regulations, and working with village liaison committees (VLCs) and village liaison officers (VLOs). Conversely, 45 % and 52 % of fishers from Kiegeani and Juani respectively were unsatisfied about their involvement in enforcement. These fishers expressed their concerns that the MIMP does not involve them in enforcement activities as had been agreed; instead the MIMP staff simply go about performing their duties. Other fishers said they are not willing to report any matters to the MIMP because some family members are involved in prohibited fishing activities, and there is an absence of foreseen benefits. One fisher said:

> "I am not satisfied because the main stakeholders in surveilling the sea are those employees of MIMP, but it would have been easier if villagers were involved. Sometimes MIMP patrol boats have no fuel, but we fishers are at sea daily; but we are demoralized, we cannot inform MIMP if we see illegal activities going on." (Interview # 52 February 2011)

[1] The responsibility to protect natural resources is for everybody.

The initial agreement had been collaborative enforcement of regulations, but according to the testimonies of key informants, cooperation has not been effective. This is due to the following reasons: fishers are not happy with park restrictions on fishing; VLOs cannot arrest fishers using illegal gear because some are family members; mistrust has arisen due to MIMP claims that VLOs are leaking intelligence about the timing of patrols; and VLOs are not compensated for their time due to limited financial resources.

3.2.3 Local understanding of MPA fisheries regulations

In order to measure the level of awareness among fishers of the regulations, respondents were asked about prohibited types of fishing gear, consequences to violators, and whether they have been involved in illegal fishing activities. The findings show that most fishers are well informed about MPA fisheries regulations (Table 7).

In terms of violating fishing regulations, fishers from the two villages gave significantly different (χ^2 = 10.950; d.f. = 1; p = 0.001) responses. More fishers in Juani (46 %) are likely to violate fisheries regulations than those in Kiegeani (9 %). Violations are significantly associated with young age ((χ^2 = 5.386; d.f. = 1; p = 0.010) and involve the use of pull nets and the lack of a fishing license. Further questioning revealed that fishers are aware of the penalties imposed for violating fisheries regulations. They mentioned that penalties include prosecution, confiscation of fishing gear and vessels, and fines depending on the severity of the violation. A slight majority (57 %, n = 61) of fishers expressed dissatisfaction about penalties imposed by the MIMP. They reported that no warning had been issued before penalties were imposed, penalties are severe, and fishers are denied the right to defend themselves against purported offences. They contended that strict and tight penalties increase poverty in their communities, particularly because they lack alternative employment opportunities, and the extent of the fish catch has decreased in fished areas. Moreover, fishers complained about the unjustified use of force, as evident in the following statement from a fisher:

> "The government has compared fishers with poachers using guns to kill wild animals. But a fisher is a poor fellow with no guns or efficient fishing vessels like MIMP speed boats. With MIMP speed boats they can easily ram your canoe and drown you." (Interview # 50 February 2011)

Responding to some of the allegations by fishers, an MIMP official explained that offenders are warned before being penalized or taken to court. Furthermore, the MIMP conducts awareness raising initiatives in villages about fisheries regulations as a way to minimize offences. The MIMP officers complained about the low level of support from the local police and poor prosecution rates by the magistrate of offenders involved in unsustainable resource utilization.

3.2.4 Fisheries resource conflicts

Majority of fishers from Kiegeani (69 %) and Juani (96 %) said there is conflict between fishers and MIMP authorities. The most common fisheries conflicts mentioned by fishers from the two villages involved prohibition of certain types of fishing gear, access rights to fishing grounds, and the use of army forces during surveillance and enforcement activities. According to fishers' testimonies, tourism has received priority from MIMP authorities, by restricting fishing in some areas in order to guarantee the quality of the industry and the aesthetic natural environment. There is also a concern that fishing zones do not meet the daily requirements of fishers in terms of fish catch numbers. Fishers said that the area is small and the abundance of fish is low compared to core zones, especially during the southern monsoon season.

Other resource conflicts are the increasing number of fishers who continue to operate in the same area, and conflicting interests among different gear users in terms of the selection of fishing grounds. The capability of fishers to fish offshore is limited by lack of experience, lack of appropriate and efficient fishing vessels, and changes in seasons related to monsoon winds. Fishers were asked about what could be done to improve MIMP management. They provided many suggestions that were divided into several categories (see Appendix 3).

4 Discussion

The aim of this study was to assess the importance of fishers' perceptions of the effectiveness of the MPA in terms of biophysical and social indicators. The evaluation compared individual fishers' perceptions with data from key informant interviews, literature reviews and personal observations. Fishers provided information on changes since the inception of the MPA in terms of the number of fishers, type of fishing gear allowed, coastal habitat conditions and fish catch. They also expressed their opinions on indicators used to assess the social acceptance and effectiveness of the MPA, such as its effects on fisheries in general, on fishers' own fishing activities, and their involvement in MPA management processes.

4.1 Effect of fishers' characteristics on perceptions of MPA outcomes

Results indicate that the primary factors that influence fishers' perceptions of MPA outcomes are fishers' area of residence and the gear they operate. Differences in perceptions between fishers from the two villages related to effects of the MPA on fisheries and on fishers' own fishing activities, levels of resource conflict, violation of MPA regulations, and the gear exchange program. The data suggest that a higher proportion of Juani fishers associated with net fishing felt adversely impacted by the MPA. Compared to fishers from Kiegeani, fishers from Juani did not agree with the suggestion that MPA has benefitted local fisheries, and more likely to violate fisheries regulations, which may be explained by the fact that net fishing is discouraged by the MIMP. Conversely, Kiegeani fishers felt less affected by the MPA in terms of their own activities; but they too did not support the suggestion that the MPA offers benefits to fisheries.

The difference in perceptions between the two communities may be attributed to the fact that Juani and Kiegeani have different fishing capacities, such as the use of motorized boats and net fishing. Fishing vessels from Juani are capable of travelling longer distances from the coast since they are slightly larger and powered by outboard engines. Kiegeani vessels are much smaller and less powerful (most are paddle canoes), and are thus limited to travelling only short distances from the coast. Therefore fishing grounds further from the coast, in the proximity of core zones, can be exploited more easily by fishers from Juani than those from Kiegeani. Moreover, most fishers in Juani use pullnet fishing locally known as *Mtando* which has high catchability in the short term. Kiegeani fishers use gears that are considered sustainable in MIMP such as handlines and fish traps.These findings are consistent with those of Blyth et al. (2002) and Hamilton (2012), namely that types of vessel and gear may influence fishers' views on MPA performance.

Consistent with the findings of McClanahan et al. (2009), reliance on marine resources may be another factor explaining the differences observed between perceptions of fishers from Kiegeani and Juani, since access to other sources of income differs significantly between the two villages. Although the majority of Kiegeani fishers perceived no benefit of the MPA to fisheries, they felt less impacted by restrictions imposed by the MIMP compared to those from Juani. Most Kiegeani fishers have other options of generating income, e.g. cash crops, animal husbandry and petty jobs, which makes them less dependent on fishing. Fishers from Kiegeani are involved in farming coconuts, whereas those from Juani are involved in farming only for the production of food. It is likely that a more detailed set of questions related to the economics of fishing and livelihood opportunities might reveal the level of income that is sufficient to generate positive perceptions of the MIMP.

4.2 Assessing the effectiveness of the MPA

The evaluation of the effectiveness of the MPA indicates that several indicators deviate negatively from MIMP objectives, while others show a positive trend (Table 8).

4.2.1 Biophysical indicators

The evaluation of biophysical indicators shows that the MIMP objective of conserving coastal habitats is likely to be achieved; however, other indicators show a deviation from MIMP objectives. The positive trends observed from fishers' perceptions concerning the status of coastal habitats indicate that communities accept and comply with park regulations that restrict destructive practices. These results are consistent with data reported in the MIMP management plan, namely that the condition of coral reefs, mangroves and seagrass is improving (URT 2011).

Areas of concern mentioned by fishers were the increasing numbers of fishers, decreasing fish catch trends and the lack of general benefits to fisheries. According to Bennett and Dearden (2014), although perceived impacts are not the same as actual impacts, they may enlighten what is happening on the ground. Thus results in this study point to a relationship between the MIMP and local communities that is likely to support or undermine the success of marine conservation initiatives in Mafia Island.

Fishers' perceptions of fishing pressure (number of fishers and types of fishing gear) did not differ significantly between the two communities. The majority of respondents reported that the number of fishers has increased, which was attributed to the lack of salaried employment. However, the MIMP report (URT 2011) shows that supplementary income generating activities have been promoted and children are supported in attending formal school in order to reduce families' dependence on fishing. It is possible that the alternative livelihood opportunities provided are considered by fishers as to be insufficient in compensating for the loss of fishing income; furthermore, community demands for support may be beyond the financial capability of the MIMP. Alternatively, fishers may have underutilized other income generating opportunities, resulting in low income and a high cost incurred by exiting the fishing industry. These possibilities require further scrutiny.

Other factors that contribute to fishing pressure may include the lack of opportunities for locals to participate in tourism activities, due to outside ownership and few opportunities for salaried employment (Rubens and Kazimoto 2003; URT 2011; Bennett and Dearden 2014). Research done by McClanahan et al. (2009) in the same area found that better access to markets or salaried employment would be more likely to influence the success of the MPA, more than increasing the number of livelihoods. In addition, fishers claimed that the effort required for fishing is increasing because of current ‘co-management’ initiatives in coastal areas. Fishers complained that they have lost access to fishing sites located outside the park because of the establishment of Beach Management Units (BMUs).Villagers outside the park do not allow fishers residing inside MIMP boundaries to fish in their areas − as a result fishing activities tend to be concentrated inside Chole bay. Thus, diversification of the coastal economy and the introduction of alternative employment opportunities, specifically oriented to young fishers, may help to deal with issues of fishers displaced from fishing.

Mafia Island has not experienced vast changes in fishing technology and the observed complex multi-gear fishery is related to ecological, economic and social aspects of the area (Gaspare, Bryceson and Kulindwa forthcoming). The MIMP has effectively removed dynamite, poison and beach seine fishing, and provided fishing tools to fishers in the quest to promote sustainable fishing. However, local fishers are not content with the gear provided by the MIMP. A key informant agreed with the complaints by fishers on the gear exchange program, attributing the problems to improper planning at local level. Many fishers stated that the cause of increased use of pull nets, which are restricted in MIMP boundaries, was decreased abundance of fish in fished zones. Contrary to what fishers claimed about pull nets, the MIMP manager said the destructiveness of pull nets is obvious since they drag the bottom of the sea and catch juveniles. Nevertheless, the destructive nature of pull nets remains a topic for debate due to the lack of documented research on the effects of the practice.

Another indicator that deviates from MIMP objectives is fish catch trends. Halpern, Lester and Kellner (2009) and Machumu and Yakupitiyage (2013) report that MPAs benefit local fisheries through increased biomass spillover; however, fishers in Mafia are not content with fish catch numbers. Some fishers mentioned that areas in which they are allowed to fish are naturally less productive, with low fish abundance compared to core zones. These findings from fishers' perceptions are inconsistent with several studies conducted elsewhere exploring fishers' perceptions of the performance of MPAs (Russ, Alcala and Maypa 2003; Leleu et al. 2012). Studies of spillover from a marine reserve in the Philippines found that fishers associated improvement in their catch size with the MPA (Russ et al. 2003; Hamilton 2012). Factors responsible for the decrease in fish catch inside the MIMP may be increasing fishing pressure in fished zones, and fishers lacking efficient fishing tools to extend their activities to larger areas. It is also likely that productive areas may be inaccessible due to distance, depth, adverse sea conditions and management regimes, thus causing fishers to continue fishing in the same areas. This may lead to localized overfishing.

Fishers in this study said they have approached MIMP authorities on the issue of lower catch numbers using set nets, but claimed that they get no response. On the other hand, MIMP officials stated that fishers are not willing to provide catch data to the authorities. This study found evidence of a lack of collaboration, trust and respect between fishers and managers, which are clearly barriers to effective co-management arrangements. According to Gibson and Marks (1995), integrating conservation and development goals is a challenging task because incentives offered to communities often overlook the socio-economic and cultural importance of local practices. In Mafia, fishers commended the MIMP for removing destructive fishing gear such as dynamite and beach seine, but decried the restrictions on using pull nets and fishing in traditional fishing grounds. As mentioned earlier, the issue of pull nets is controversial and is complicated by ineffective enforcement in areas outside the MPA. As a result, restrictions inside the park are interpreted by some park resident fishers as oppression. Hence there is a need to develop a management strategy that nurtures sustainability of the entire seascape, rather than only in the MPA (Hughes et al. 2005).

Consistent with reports about decreasing fish catch trends, highly negative attitudes towards the MPA were evident in this study. This may indicate that core zones do not compensate for the loss of fishing grounds through spillovers. Contrary to fishers' perceptions, Marine Park managers were optimistic about the ecological outcomes of the MIMP. Nevertheless, long-term monitoring data on fishing effort and catch are lacking, thus making it difficult to quantify the actual yield from the fishery. It is possible that fishers' perceptions of decreased fish catch and negative perceptions of the MPA found in this study may not mean that the MIMP is ineffective in promoting sustainable resource utilization. Fishers tend to support MPAs when they perceive benefits to their own fishing experiences (such as increases in fish catch and providing nursery grounds for fish) (Gelcich, Castilla and Godoy 2009; Leleu et al. 2012). Thus, a possible interpretation for the negative attitudes might be that increased fish abundance in core zones attracts many people to join the fishery; however, enforcement is excessive in communities that rely on fishing for their livelihoods.

4.2.2 Governance indicators

The evaluation of governance indicators is mixed, with two indicators being rated positive in both villages. The degree of awareness and level of violation of fisheries regulations both indicate positive changes, thus implying that the MIMP has effectively informed fishers about fishing regulations. The level of involvement in management processes and the level of resource conflict show negative changes in both villages; involvement in enforcement was rated negative in one village and positive in the other village.

In line with other studies exploring the impact of fishers' involvement in effective management of MPAs (Pollnac, Crawford and Gorospe 2001; Charles and Wilson (2009); Kincaid et al. 2014), this study found that involvement in MIMP planning and implementation has significant impacts on fishers' support for the initiative. Fishers who are satisfied with their level of involvement in MIMP planning are more supportive thereof. However, the majority of interviewed fishers are dissatisfied with their involvement in MPA planning and management. Warner and Pomeroy (2012) assert that the rapid onset and enforcement of regulations at the inception of an MPA might increase resistance and non-compliance. The same authors suggest that enforcement might be implemented gradually, or at later stages in MPA management. However in Mafia, fishers complained that the MIMP has changed the initial agreement – this may be due to the gradual implementation of the management plan and the delay in formulating MPA regulations[2]. Before regulations were in force, the MIMP had no legal power to arrest violators, but as things have progressed, they have become stricter and the regulations now support prosecutions. Another explanation may be the quality of local participation at the time of planning the establishment of the MIMP, which has been the subject of discussion by other researchers (Mwaipopo 2008; January and Ngowi 2010). Charles and Wilson (2009) found that initial participation of resource users is an important aspect of the rationale in developing MPA objectives.

[2] MIMP regulations were formulated only in 2006, ten years after inception of the park.

This study found that fishers in Mafia had participated in identifying sensitive areas that were in need of protection. This was because several sources of information were needed to create a richer set of knowledge for effective implementation of the management plan. However, involvement was perceived by fishers as a means to make conservation measures less likely to meet with local resistance. This sentiment expressed by fishers indicates a clear lack of initial understanding of MIMP objectives, which, together with the lack of a transparent planning process, could be the cause of resistance against fishery closures. Christie et al. (2003) affirm that a key requirement for the success of MPAs is entry to communities that utilize fisheries resources in order to gain local support at the implementation stage. Thus, the lack of fishers' understanding of the implications of the MIMP at the initial stage may be responsible for their resistance and lack of support for fisheries closures in Mafia.

In addition to local level involvement, education and awareness also contribute to local support of MPAs, reduce the use of destructive fishing gear, and increase compliance with fisheries regulations (Slater, Mgaya and Stead 2014). This study found a high level of awareness about MPA regulations in the two communities, indicating that the MIMP has an effective information dissemination program. However, local awareness of the MPA has done little to enhance acceptance thereof in both villages. Fishers' lack of access and user rights to fishing grounds, as well as restrictions on fishing gear have accelerated conflicts which have continued unresolved, 16 years after the park's implementation (Walley 2004; McClanahan et al. 2009; Benjamisen and Bryceson 2012). It is likely that support for the MPA may not be achieved unless proactive and ongoing management measures are put in place to reduce conflict between fishers and managers.

Before drawing conclusions from this evaluation, it is important to note several caveats of this study. The study involved only two out of thirteen villages located inside the MIMP; therefore results on effectiveness of the MIMP cannot be generalized. Nevertheless, this study does provide useful insights into the trends of fishers' perceptions towards MPAs, which may aid in the design of a more comprehensive study in the future. Any future studies on assessment of effectiveness of MPAs should aim to collect data from a larger sample size of fishers in order to generalize the results. Further, it is obvious from field observations that some villages with a high dependence on fishing do not support the MPA because of restrictions related to fishing gear and core zones. In one village, fishers frequently asked about the purpose of this research and repeatedly claimed that the researcher was working for the MPA, despite explanations about her, where she comes from, and the reasons for conducting the research. They explained that they had had previous experience of a person who came to the village to do similar research, and later that person returned to work for the MIMP as an enforcement officer and confiscated their fishing gear. Skepticism among fishers about the purpose and outcomes of this research study may have influenced their opinions. In line with Garces et al. (2012), this highlights the importance of considering community characteristics when evaluating MPA performance and correlating fishers' perceptions with available scientific findings or any other sources of information.

5. Conclusions

This study found that in the Mafia Island Marine Park – an MPA with well established core zones (created 16 years ago) – fishers' perceptions of the biophysical and governance indicators of MPA effectiveness were either positive, negative or they had no opinion. Several factors should be taken into account when analyzing fishers' perceptions, including local geographic conditions, access to other sources of income, fishing capacity, age of fishers, and type of fishing gear in use. While there is no doubt that the MPA has benefitted the conservation of targeted fish species and associated marine habitats, its benefits to small-scale fishers remain unclear. Most fishers appeared unconvinced about its effectiveness, as a result of increasing fishing pressure, decreasing trends in fish catch, and the lack of MPA benefits to their own activity and small-scale fisheries in general. It should be noted that fishers' responses to some indicators varied between the two communities sampled for this study. The community with a high degree of reliance on fishing for their livelihood, nets and motorized vessels felt more MPA effects on their own activities and were more likely to violate MPA regulations than the other community. Negative perceptions can therefore be associated with MIMP restrictions on net fishing and area closures.

The participation of local communities in fisheries management is believed to be an important practice in encouraging information exchange and collaboration, increasing management effectiveness, and reducing conflicts and enforcement costs (Bennett and Dearden 2014). Similarly, findings in this study suggest that positive perceptions of fishers' involvement in MPA planning are associated with perceived benefits of the MPA on their own fishing activities. Consequently, policy prescriptions based on the involvement of resource users in the design, implementation and functioning of management tools are likely to create good outcomes (Cinner et al. 2012).

Nevertheless, the results of this study underline a deviation between fishers' perceptions and information found in the MIMP general management plan (URT 2011) regarding fish catch trends, and MPA effects on fisheries, gear management, and levels of conflict. This study suggests that efforts focused on improving access to sustainable income sources, promoting the use of sustainable fishing gear, and developing legal frameworks that support local knowledge and practices may render fisheries management practices more effective. Finally, while the MIMP is clearly focusing on dealing with threats originating at the local level, it is time to consider global forces that might affect the sustainability of fisheries utilization, including large-scale fisheries and climate change.

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Table 1: Summary of permitted activities in the MIMP by zone (URT 2011)

Activity	Core zone	Specified-use zone		General-use zone	
	All users	**Residents**	**Others**	**Residents**	**Others**
Handlines, box traps, fence traps	X	LRUC	X	LRUC	P
Long lines	X	X	X	LRUC	P
[1]Pull nets (of any size entirely prohibited)	X	X	X	X	X
[2]Set nets/shark nets 3-7" mesh	X	LRUC	X	LRUC	P
Shark nets more than 7" mesh	X	X	X	LRUC	P
Sport fishing	X	X	X	LRUC	P
Aquarium collection (all organisms including corals)	X	X	X	P	X
Coral mining from intertidal or sub-tidal areas	X	X	X	P	X
Mangrove cutting (subsistence)	X	X	X	P	P
Sea weed/sea grass collection (wild)	X	X	X	LRUC	P
Scuba diving for tourism	P	P	P	P	P
Snorkeling, swimming for tourism	Freely allowed	Freely allowed	Freely allowed	Freely allowed	Freely allowed
Overnight boat mooring for tourism	X	X	X	P	P

X = Not permitted, LRUC = Local Resident User Certificate required, P = MIMP permit required from MIMP/village.

[1] Pull nets: includes nets known locally as *mtando*, *nyavu za kuzungusha*, *nyavu za kuvuta*, and *mtambo* all are entirely prohibited

[2] Set nets > 3" or > 7": include gill nets (*nyavu za kupweleza)* and shark nets (*jarife*)

Table 2: Factors contributing to the increase in number of fishers, compared to before inception of the MPA (n = 54)

Causes of increase	% of respondents
Lack of alternative employment opportunities	47
Lack of opportunities for post-primary education	39
Population increase	20
Easy and quick way of earning cash money	20
Immigrant fishers from other parts of Tanzania	6
Changes in fishing techniques	4

Note: the total percentage is more than 100 because some respondents gave more than one reason

Table 3: Reasons stated by fishers for dissatisfaction concerning the MIMP gear exchange program (n = 22)

Explanation	Stated reason	%
Fishing practices preferred by fishers are restricted inside the MIMP	− Fishers are not free to fish because of MIMP restrictions	23
	− A way to deceive fishers in order to support gear restrictions	14
Lack of training on how to use the gear	− No training on how to use the gear	14
	− Fishers were provided with loans but not trained in cooperative business arrangements and savings	5
Improper planning and monitoring of the ecological and social performance of fishing gear provided	− No follow up from MIMP to see what fishers were getting	5
	− MIMP targeted few fishers who were using pull nets, but no other fishers	14
	− Beneficiaries have a better life and were seen to subordinate and marginalize others	5
	− Set-net fishing is not efficient because of decreased fish abundance in shallow waters	18
	− Numbers of fishers and fishing vessels have increased	5

Note: the total percentage is more than 100 because some respondents gave more than one reason

Table 4: Factors contributing to the declining fish catch trend, compared to before inception of the MIMP (n = 37)

Causes of declining fish catch trend	% of respondents
Overharvesting fisheries resources	26
Increased market price for fish	22
Destructive fishing practices	15
Restriction of productive fishing grounds	19
Fish have migrated to deeper areas	15
God's will	4

Table 5: Fishers' opinions on the effects of core zones on fisheries

Reasons	% of fishers
Positive opinions (n = 20)	
Fish reproduce in core zones and move to fished areas (spillover)	56
No damaging fishing gear	12
Fish are abundant in core zones	12
Slight increase in fish catch	12
Village receives tourism revenues from MIMP	8
No benefits (n = 41)	
Fish are abundant in core zones but do not move to fished areas	46
Restriction of fishing grounds	39
Lack of fishing vessels to fish in locations near core zones	15

Table 6: Reasons for negative perceptions about MPA effects on fishing activities (n = 36)

Reasons	**% of fishers**
Low income due to lack of freedom in fishing caused by fear of MIMP monitors and confiscation of fishing gear	55
Fishing restrictions in areas where fish are abundant	36
Lack of financial support from MIMP	12
Pull nets are not allowed	12

Table 7: Awareness of prohibited fishing gear types and fishers' perceptions of consequences of breaking fisheries regulations (n = 61)

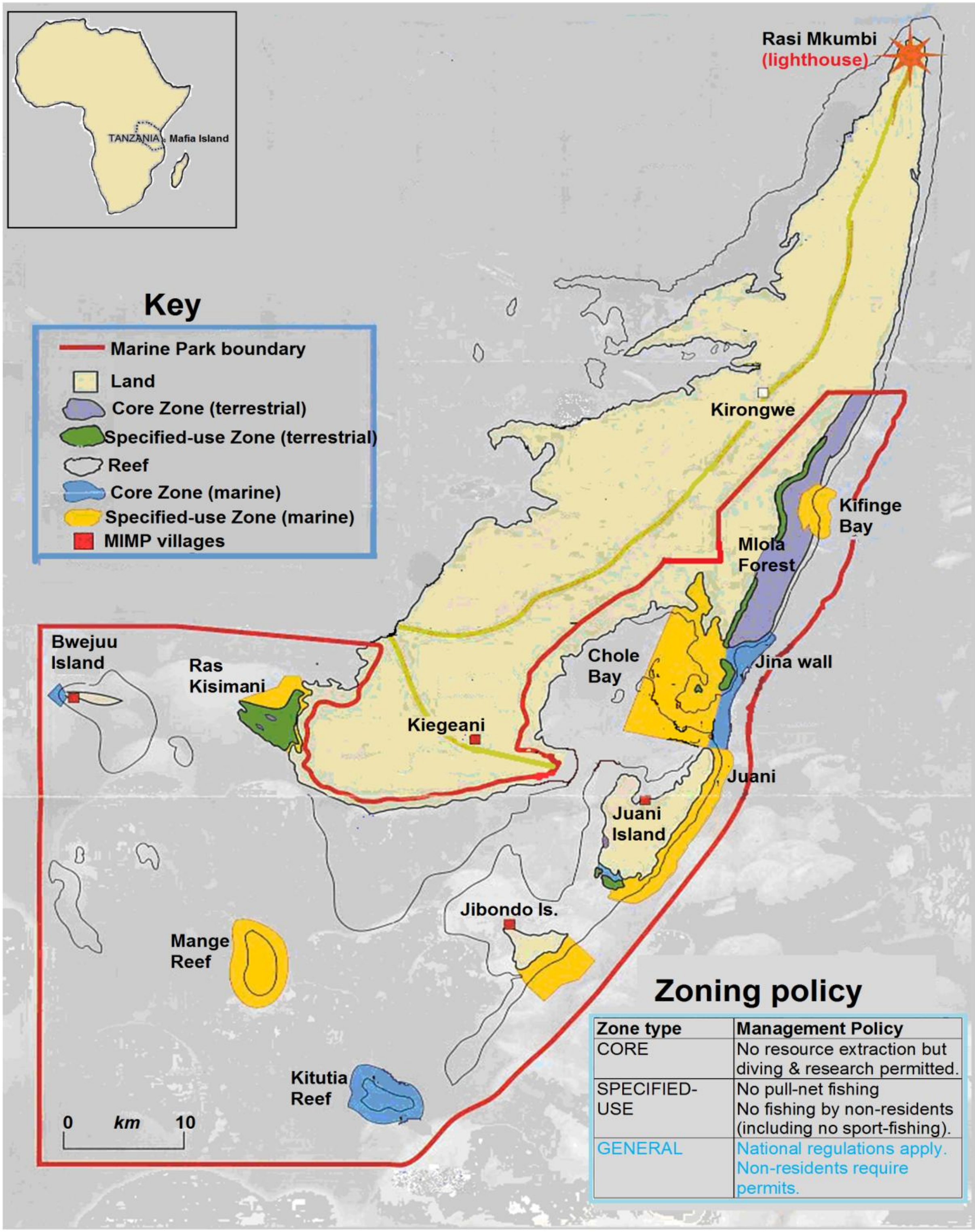
Questions	**Response category**	**Number of responses**	**% of responses**
Have you ever been asked to stop using any kind of fishing gear? (100 % answered yes)	Nets with small mesh size (< 2.5 inches)	36	59
	Pull nets	43	71
	Dynamite	26	43
	Poison	21	34
	Harpoon	9	14
	Gill netting by beating water	2	4
	All gear types	1	2
	Do not know	1	2
Have you ever been involved in any illegal fishing activities?	No, I use legal gear	44	72
	Yes, use of pull nets	10	17
	Yes, no license	6	11
What are the consequences of violating regulations?	Prosecution	30	49
	Confiscation of fishing gear	30	49
	Paying fines	10	16
	Do not know	12	19

A multi-response frame was used. Hence the total percentage is more than 100.

Table 8: Evaluation rating for some indicators (Pomeroy et al. 2005) assessed in the Mafia Island Marine Park

Indicator category	**Indicator name**	**Kiegeani**	**Juani**	**MIMP progress (URT 2011) and statements by officials**
Biophysical	− Changes in fishing efforts (number of fishers, fishing gear and vessel types)	-	-	-
	− Use of destructive fishing methods (dynamite, beach seine)	+	+	+
	− Fishing gear received from MIMP	?	-	+
	− Condition of coastal habitats (coral reefs, mangroves and seagrass)	+	+	+
	− Fish catch trends	-	-	?(+)
	− Perceived effects of MPA on fisheries in general	-	-	+
	− Perceived effects of MPA on fishers' own fishing activities	+	-	+
Governance	− Level of fishers' participation and satisfaction in management process	-	-	+
	− Level of fishers' involvement in surveillance and enforcement	+	-	+
	− Local understanding of MPA rules and regulations	+	+	+
	− Violation of MPA regulations	+	+	-
	− Level of resource conflict	-	-	?

Note: '+' means positive change (towards meeting MIMP objectives i.e. perceived by more than 50 % of total respondents); '-' means negative change (in a direction away from MIMP objectives i.e. perceived by more than 50 % of total respondents); and '?' means that the trend is uncertain. This rating system was adapted from Garces et al. (2012).



Zone type	Management Policy
CORE	No resource extraction but diving & research permitted.
SPECIFIED-USE	No pull-net fishing No fishing by non-residents (including no sport-fishing).
GENERAL	National regulations apply. Non-residents require permits.

Figure 1: Mafia Island Marine Protected Area and management scheme

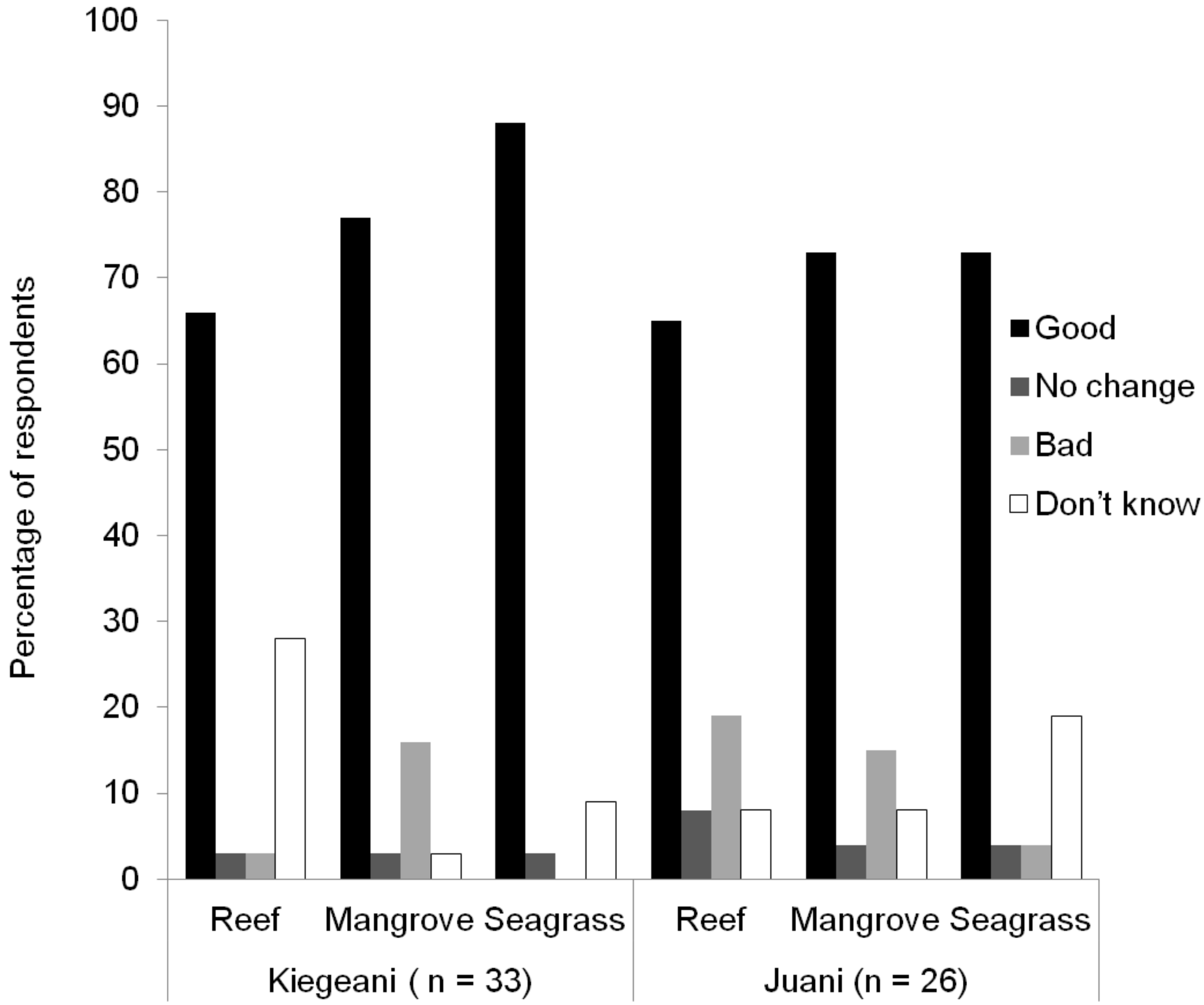


Figure 2: Fishers' perceptions of current conditions of coastal habitats inside the MIMP (expressed in percentages of respondents)

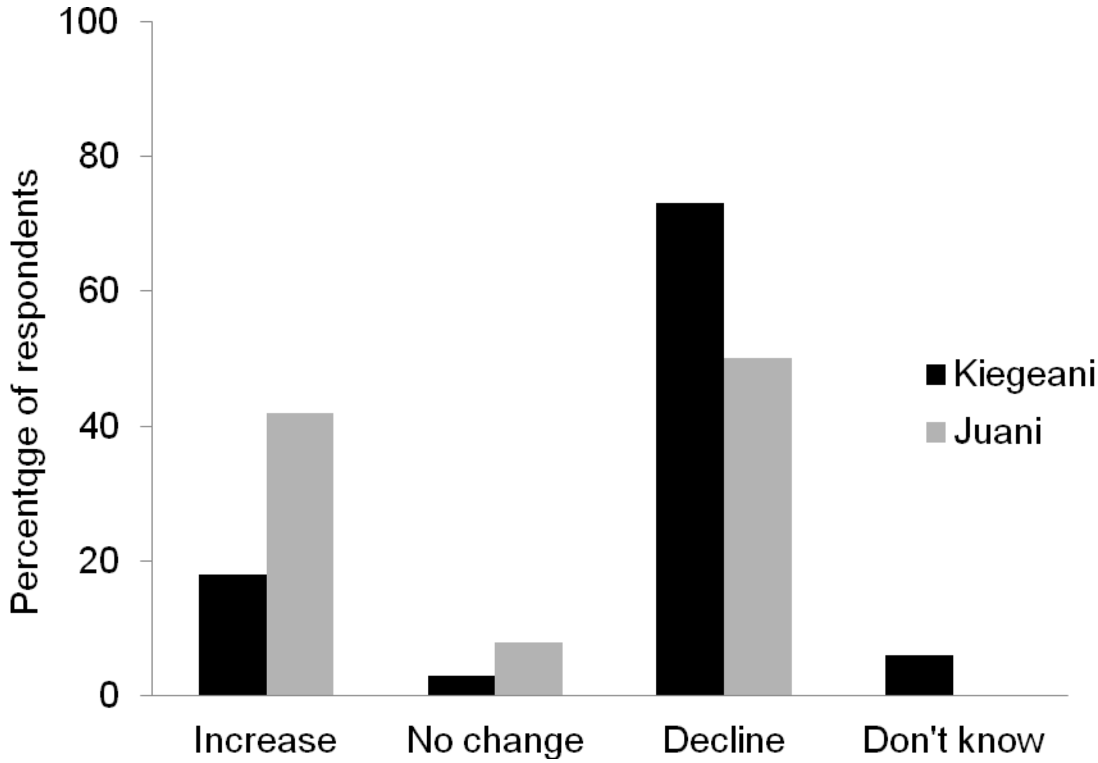


Figure 3: Fishers' perceptions of the current fish catch trend, compared to before the inception of the MIMP

Appendix 1: Questions asked during interviews with fishers (open-ended questionnaire) and categories used in statistical analysis to explore the influence of fishers' characteristics and perceptions of MPA effectiveness indicators

	Questions	Possible answers
1.	Area of residence	− Kiegeani − Juani
2.	Age of fisher	− 35 years or less − More than 36 years
3.	How many years have you been fishing in this area?	− 20 years or less − More than 21 years
4.	Do you have access to other sources of income?	− Yes (coconuts farm, petty trade and casual job) − No (Only farming for food)
5.	Which major fishing gear type do you practice nowadays?	− Static (hook-and-line , basket traps , harpoon) − Net (seine net, shark net, small gill net)
6.	What type of fishing vessel you use?	− Motorized boat (wooden planked boats) − Non-motorized (no vessel, outrigger canoe, dugout canoe)
7.	What has happened to the …….… since the MIMP?	− Increased − Decreased − No change
−	Number of fishers	− Do not know
−	Fishing gear	
−	Number of fish	
8.	What has happened to the condition of coral reefs, seagrass and mangroves since the MIMP?	− Good − No change − Bad − Do not know
9.	What were the objectives of implementing the MIMP?	
10.	What are the effects of core zones on your own activity?	− Positive − Neutral
11.	What are the effects of core zones on fisheries in general?	− Negative − Don't know
12.	How satisfied are you with ………	− Satisfied
−	Participation in planning process of the MIMP?	− Neutral − Dissatisfied
−	Participation in surveillance, enforcement and monitoring of fisheries resources?	
−	Alternative fishing gear from the MIMP?	

13. Is there any conflict involving fishers and fisheries management authorities?	− Yes − No − Don’t know

Appendix 2: Factors influencing fishers' perceptions of various MPA effectiveness indicators based on Chi Square cross-tabulation and multinomial logistic regression analysis, depending on the number of categories of each variable as shown in Appendix 1. Variables included are those that remained after the step-wise screening procedure (*p < 0.05)

	Statistical results					
Variables	**Area of residence**	**Age**	**Fishing experience**	**Sources of income**	**Gear type**	**Vessel type**
Area of residence	-	0868	0.346	0.004*	0.025*	0.011*
Age of a fisher	-	-	0.001*	0.098	0.027*	0.691
Fishing experience	-	-	-	0.451	0.044*	0.984
Access to other sources of income	-	-	-	-	0.444	0.905
Gear type	-	-	-	-	-	0.0001*
Vessel type	-	-	-	-	-	-
Effects of core zones on your own activity	0.023*	0036*	0.207	0.571	0.002*	0.0001*
Effects of core zones on fisheries in general	0.007*	0734	0.459	0.125	0.680	0.330
Participation in planning process of the MIMP	0.498	0873	0.306	0.847	0.213	0.773
Participation in surveillance, enforcement and monitoring of fisheries resources	0.771	0.885	0.754	0.425	0.444	0.905
Violation of fisheries regulations	0.001*	0.010*	0.159	0.670	0.017*	0.009*

Appendix 3: Responses to the question "What should the MIMP do for fisheries and conservation?" Responses are divided into categories for ease of presentation (table design is adapted from Kincaid et al. 2014).

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1. Enforcement of regulations

1.1 Continue to restrict dynamite, pull nets and beach seine fishing

1.2 Continue with surveillance of the sea

1.3 Increase the number of patrols

1.4 Fishers should take care of fisheries resources by imposing strict sanctions on themselves

1.5 Fishers should practice responsible fishing so as not to damage the marine environment

1.6 Communities should participate in monitoring and surveillance of the sea and reporting of illegal fishing activities to authorities

1.7 Fisheries regulations should not be generalized for the whole country; they should consider the nature of the area and people living there

1.8 They should leave fishers alone with their work and should not think that fishers are getting a lot of money. What fishers are getting is money for school fees for their children

1.9 Enforcement is focusing only on small-scale fishers not on large-scale fishing

2. Fishing gear

2.1 Fishers should be provided with fishing tools they need e.g. boats and engines

2.2 Fishers should be provided with fishing gear which is not destructive and matches the local environment e.g. fish aggregating device (FAD).

2.3 Support for fishing gear should be given to all members in a fishing group

2.4 Marine park is good, they should provide fishing tools to Kiegeani fishers

2.5 Fishers should be trained on how to use new fishing gear

2.6 *Mtando* should be allowed, it is not destructive

2.7 Fishers should use fishing gear that is not destructive e.g. shark nets, basket traps and hook-and-line

3. Education/communication

3.1 Fishers should be educated on marine conservation

3.2 Help fishers so that they can be united and work together as a group, not individuals

3.3 Design new effective ways of communication among leaders from village to national level

3.4 Educate fishers on the impact of destructive fishing gear

3.5 More education on sustainable use of the sea, other fishers are doing things because of ignorance. This can be achieved using village meetings and school curriculum. "Education is Light"

3.6 Fishers should be trained on how to use money from fishing

3.7 Village leaders should bring feedback to the village from meetings at higher levels

3.8 Local knowledge and practices need to be respected e.g. one fisher said "How can someone use a bag of sand as an anchor?"

4. Zoning schemes

4.1 Fishers should be allowed to fish everywhere

4.2 Reduce restrictions on fishing

4.3 Rezoning to allow fishers to access some areas of core zones and only require Kinasi pass for tourists

4.4 Set aside areas for all types of fishing and reserve areas, as it was agreed from beginning of the program; MIMP changed it without involving villagers

5. Alternative livelihood opportunities

5.1 Support fishers to do land-based activities then close the sea from fishing

5.2 Once fishers have money they will guard the sea themselves. “A person cannot be a guard while hungry”.

5.3 Fishers should be assisted in finding markets for fish

5.4 No need of support − everyone should be on his own

6. Closed seasons

6.1 More research to know which area at what time of the year there are big fish; then handlines can be allowed in core zone at a certain time of the year

6.2 The sea closes itself, fishing should be inside Chole Bay during southern monsoon and far offshore during northern monsoon

6.3 Fishers move from one fishing ground to another depending on tidal cycles and mend nets, leaving fishing sites to replenish

7. Resolving conflicts/agreements

7.1 Fishers and MIMP should sit together at the negotiating table to review previous agreements and plan for the future

7.2 They should stop humiliating fishers and valuing tourists

APPENDICES

Appendix 1: Questions about fishing practices

1. Age of fisher
2. Place of birth
3. Years lived in the village
4. What are your main sources of income?
5. What other income generating activities you do?
6. How did you learn to fish?
7. Why did you choose to become a fisher?
8. How long have you been fishing?
9. Which way do you use to learn new fishing techniques and from whom?
10. Which major traditional fishing type do you practice?
11. What problems are you facing in using that kind of gear? And how are you overcoming those problems?
12. What kind of gear do you think should not be used in fishing?
13. Where do you mainly go for your fishing activities nowadays?
14. What criteria do you use to select a particular fishing ground?
15. How much time do you spend fishing per week?
16. Which method you use to catch more fish in a day?
17. If you find a place where there are many fish, do you tell your fellow fishers to come and fish there?
18. What are the most common grouper species you catch?
19. Is there a fishing season for groupers?
20. Where do you catch groupers (fishing grounds)?

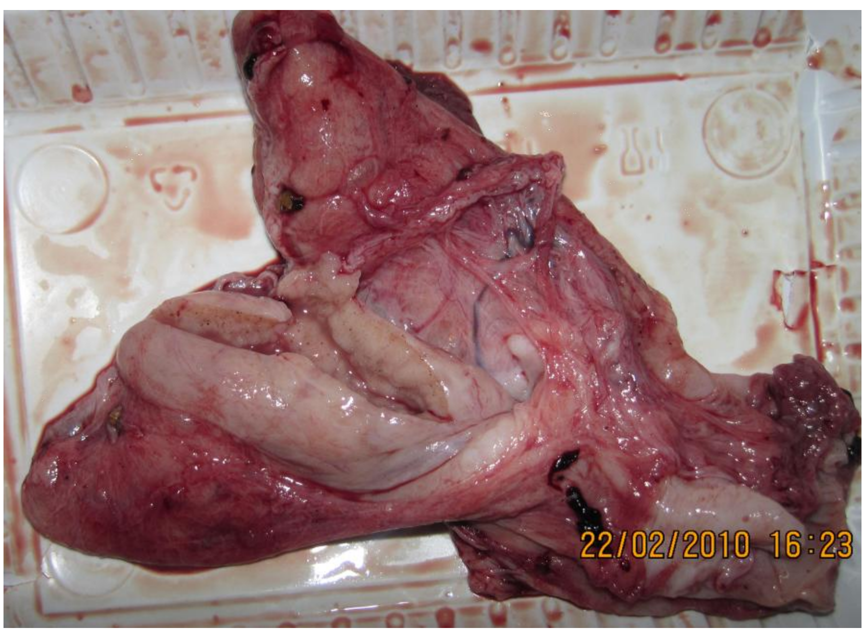
21. What customary practices you are supposed to carry out before going fishing?
22. What customary practices you are not supposed to do when fishing?
23. What customary or traditional activities may make you decide not to go fishing?
24. What social activities may make you decide not to go fishing?

Appendix 2: Interview guide for key informants on the ecology and biology of groupers

1. List all the major species of grouper that you know (local names)
2. Describe the environment inhabited by groupers
3. Where can the smaller individuals be found? And the large ones?
4. Where is the spawning and reproduction zone of groupers?
5. Can you differentiate between female and male groupers?
6. Have you ever seen or caught many groupers at the same place? If so when? And where?
7. What do groupers eat?
8. Do the larger individuals eat the same as the smaller individuals?
9. What predators exist for groupers?
10. Do groupers migrate?
11. What techniques do you use for catching/fishing for groupers? Mention all types and describe how they work.
12. When is the peak grouper fishing season? Are groupers caught at other times of the year?
13. What is the best time for catching groupers? Day or night, and why?
14. What threats are facing groupers species in Mafia Island?

Appendix 3: Macroscopic examination of gonads

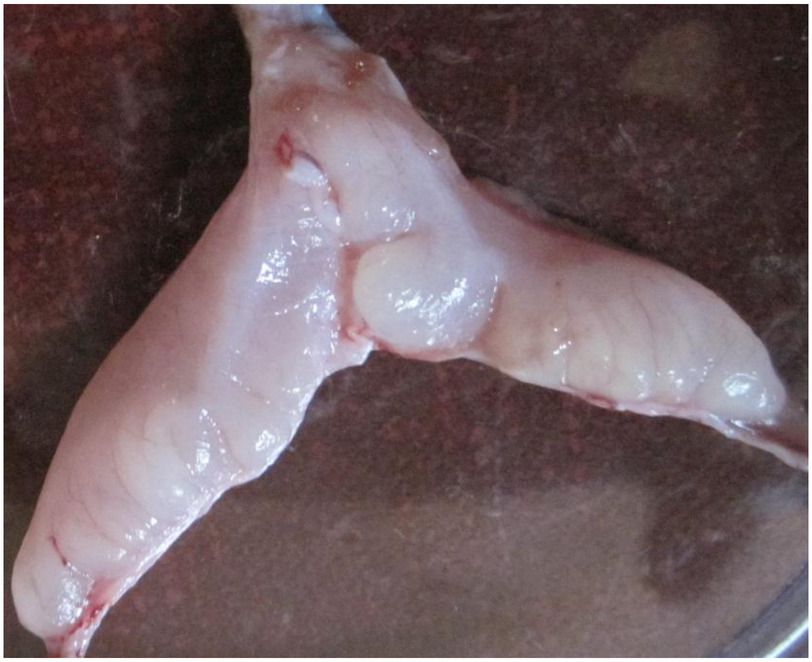
Mature male gonad (*Epinephelus fuscoguttatus*: length = 89 cm, weight = 15.4 kg, GW = 372.4 g)



Immature male gonad growing in an old sac (*E. malabaricus*: length 114 cm, weight 37 kg, GW 72.06g)

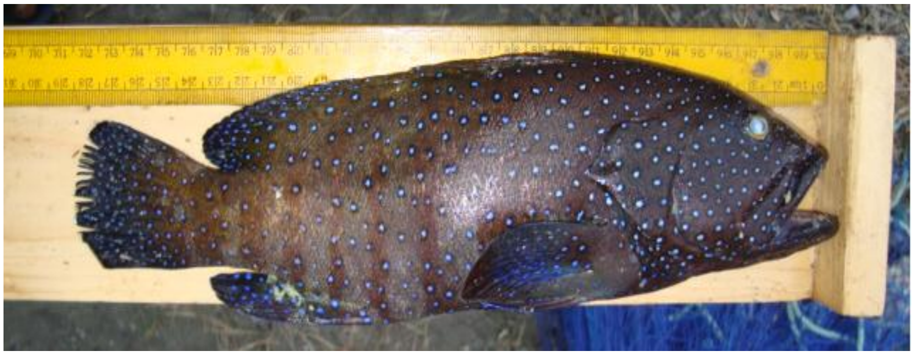
Female gonad after spawning (*E. malabaricus*: length = 104.5 cm, weight = 17.7 kg, GW = 26.87 g).

Mature female gonad (*E. malabaricus*: length = 96.5 cm, weight = 16.5 kg, GW = 153.43 g).


Immature female gonad ((*E. malabaricus*: length = 66.3 cm, weight = 4.7 kg, GW = 4.4 g).

Appendix 4: Species of groupers identified in Mafia Island

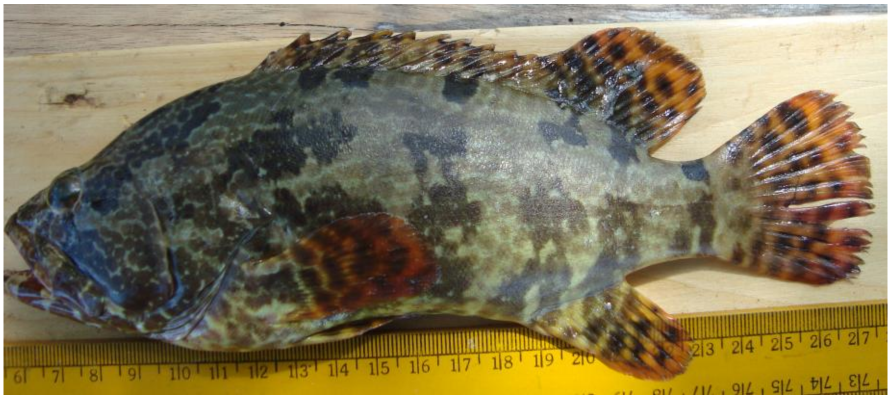
Cephalopholis aurantia



cephalopholis argus

cephalopholis miniata

Epinephelus malabaricus



Epinephelus fuscogutattus

Epinephelus hexagonatus

Epinephelus merra

Epinephelus faveatus


Epinephelus spilotoceps

Epinephelus melanostigma

Epinephelus longispinis

Epinephelus spp

Cephalopholis nigripinnis

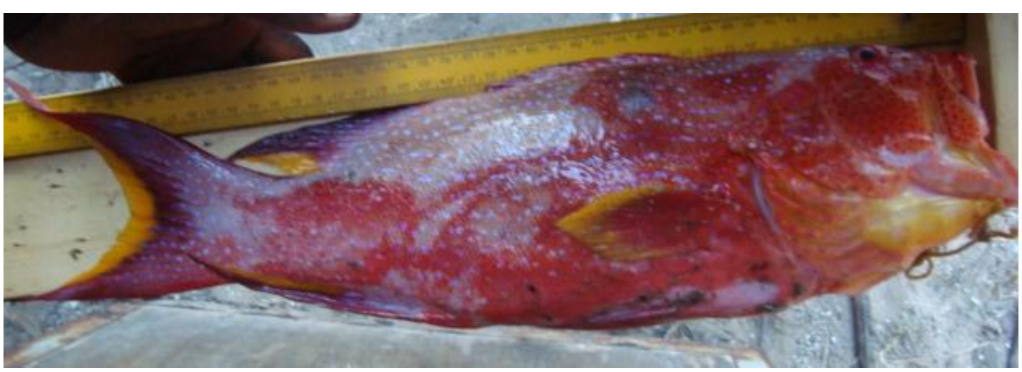
Epinephelus fasciatus

Epinephelus coioides

Plectropomus spp

Plectropomus laevis

Epinephelus caeruleopunctatus



Valiola louti

Plectropomus sp


Aethaloperca rogaa

Epinephelus microdon

Dermatolepis striolata


Epinephelus tukula

Appendix 5 Fishing gear and vessels found in Mafia Island

Construction of a basket trap used to catch large groupers

Basket trap

Large hook-and-line

Shark net

Gill net


Outrigger canoe

Mashua

Dau

Canoe


Confiscated nets at MIMP head office