UNIVERSITEIT GENT

FACULTY OF SCIENCES

Marine Biology Ghent University

Ecological and socio-economic assessment of Kenyan coastal fisheries: The case of Malindi-Ungwana Bay artisanal fisheries *versus* semi-industrial bottom trawling

UGent Promoter:

Prof. Dr. Ann Vanreusel

Kenyan Promoter:

Dr. Edward Kimani

Cosmas Nzaka MUNGA

September 2013

vliruos SHARING MINDS, CHANGING LIVES

SWIOFP

Marine Biology
Ghent University

Ecological and socio-economic assessment of Kenyan coastal fisheries:

The case of Malindi-Ungwana Bay artisanal fisheries *versus* semi-industrial bottom trawling

Cosmas Nzaka Munga

Kenya Marine and Fisheries Research Institute

Marine Fisheries and Ecology Programme

P.O. Box 81651 – 80100, Mombasa, Kenya

UGent Promoter

Prof. Dr. Ann Vanreusel

Gent University

Marine Biology Research Group

Krijgslaan 281-S8, 9000 Gent, Belgium

Kenyan Promoter

Dr. Edward Ndirui Kimani

Coordinator, Marine Fisheries and Ecology Programme

Kenya Marine and Fisheries Research Institute

P.O. Box 81651 – 80100, Mombasa, Kenya

Thesis submitted in partial fulfilment of the requirements for the Degree of Doctor in Science:
Marine Sciences

Members of the Reading Committee:

Prof. Dr. Magda Vincx	-	Gent University, Belgium
Dr. Hans Polet	-	ILVO, Belgium
Prof. Dr. Steven Degraer	-	RBINS & Gent University, Belgium

Members of the Examination Committee:

Prof. Dr. Dominique Adriaens	-	Gent University, Belgium
Prof. Dr. Magda Vincx	-	Gent University, Belgium
Dr. Hans Polet	-	ILVO, Belgium
Prof. Dr. Steven Degraer	-	RBINS & Gent University, Belgium
Prof. Dr. Nico Koedam	-	Vrije Universiteit Brussel, Belgium
Dr. Marijn Rabaut	-	North Sea Advisor Belgian Minister of North Sea & Gent University, Belgium
Dr. Edward Kimani	-	KMFRI, Kenya
Prof. Dr. Ann Vanreusel	-	Gent University, Belgium
Prof. Dr. Jan Mees	-	VLIZ & Gent University, Belgium
Dr. Marleen De Troch	-	Gent University, Belgium

Gent University

Faculty of Science

Marine Biology Research Group

Campus Sterre – S8

Krijgslaan 281

B-9000, Gent

Belgium

Email: cosmasnke2001@yahoo.com/cmunga@kmfri.co.ke

UNIVERSITEIT GENT

Publically defended on 23rd September 2013.

Chairman of the defence: Prof. Dr. Dominique Adriaens, Gent University, Belgium.

For citation of published work reprinted in this thesis, please refer to the original publications.

Munga, C.N. , 2013. Ecological and socio-economic assessment of Kenyan coastal fisheries: The case of Malindi-Ungwana Bay artisanal fisheries *versus* semi-industrial bottom trawling. Gent University, Belgium 210 pp.

Dedication

Two individuals who wanted the best out of me:

To my late father, Munga Nzaka Dingwanga who valued education despite having not been to school.

To my late brother-in-law, Shaban Zuma Ngome for his academic encouragement even up to the time of his death.

"Knowledge is like a garden if it's not cultivated, it cannot be harvested" (Kenyan Proverb)

"Wealth that is free for all is valued by none ... the fish in the sea are valueless to the fisherman, because there is no assurance that they will be there for him tomorrow if they are left behind today" (Gordon, 1954)

Acknowledgements

Every long journey begins with a single step. This marks the end of my Ph.D. programme after four years of hard work. This successful ending would not have been possible without the support in many ways from a number of institutions and individuals. First: my heartfelt and sincere gratitude go to the Flemish Inter-University Council for awarding me financial support through the VLIR ICP Ph.D. scholarship. programme. Second: to my UGent Promoter, Prof. Dr. Ann Vanreusel who started mentoring me tirelessly way back since my master program in Ecological Marine Management (ECOMAMA), currently Oceans and Lakes, while at the Free University of Brussels, from my nascency in marine science until this advanced stage. Thank you so much for your professional guidance and encouragement even at times when things were difficult, you treated me with much care and concern like one of your sons. Third: to my Kenyan Promoter and my colleague at the Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa, for having been more than just a workmate, many thanks for having shared your great and long term experience in the field of fisheries research whole-heartedly without any reservations. You have been my greatest inspiration, and I am still looking forward to continue working with you.

My Ph.D. programme would not have been complete without the sea time provided to me to participate in scientific ship cruises under the just ended South West Indian Ocean Fisheries Project (SWIOFP) in Kenya. My participation in the cruises was positively and readily accepted by Dr. Renison Ruwa (KMFRI Deputy Director, Coastal and Marine Division), who was the project National Focal Point for Kenya, Prof. Johan Groeneveld, who was the project Regional Component 2 Coordinator, and Ms. Teresa Athyde who was in-charge of cruise logistics and planning. The Kenya Navy kindly provided us with the needed sea security during the sea time. I thank you all for having given me the golden field work opportunity and indeed a great exposure.

I would wish to extend my thanks to the Director of KMFRI, Dr. Johnson Kazungu. He is the one who hinted me about the importance of Malindi-Ungwana Bay fisheries as a national interest. He challenged me right in his office during one of my courtesy calls to come up with a scientific research proposal to contribute information for the sustainable utilisation of the bay's fisheries resources. This is the very insight, which culminated in this Ph.D. study. I would also extend my thanks to the entire KMFRI management for various support given to me while undertaking my study. This is especially the office transport (field vehicles) that was readily availed to me upon request. My colleagues in KMFRI Fisheries Research Programme: James Gonda, Boaz Orembo, Rashid Anam and Dickson Odongo, thank you very much for sharing your experience and knowledge in fish identification while working with you in the various fish landing sites. Not forgeting my other colleagues in KMFRI Socio-economic Programme: Jacob Ochiewo, Edward Waiyaki, Fridah Munyi and Faith Kimanga. Many thanks for sharing your socio-economic experience with me and the great fieldwork we had together. My colleagues in the Marine Biology Research Group at Gent University: Lilian Nduku, Rasha Sabeel and Eva, many thanks for your encouragement during the tough times we underwent together. Not forgeting my Land Lady, Barbara who always reserved for me a room for my accomodation while in session at Gent, many thanks for your generosity. To my Belgian friends: Arne and Gijs, and not forgeting all Kenyan student fraternity at Gent, many thanks for making me comfortable while at Gent.

Last but not least, to my dear family for their patience and prayers while I was away from home for many years, you have made me proud of you. My mum, Regina Munga for seeing me through all my education from difficult beginings especially after being widowed, you never gave up, but you made sure I had the best in education. This was possible with great support from my brother and sister Emmanuel Ndegwa and Priscar Mbetsa. Not forgetting my nephews and nieces: Eunice Luvuno, Francis Ngome, Loice Kwekwe and

Sammy Chimvatsi. To my dear one, loving wife Gladys Njoki, the strongest of all in my family, for having endured lonely times while taking care of our son Ivan Munga and daughter Tanya Waruguru, thank you so much for your great support. Your strong prayers and continuous encouragement have finally borne fruits, there we are, Dr. and Mrs. Munga Cosmas Nzaka!

Summary

This Ph.D. study assessed the ecological and socio-economic aspects of the artisanal fishery and semi-industrial bottom trawling in the Malindi-Ungwana Bay, Kenya before and after the trawl ban. Bottom trawling targets shrimps but also produce bycatch. For several decades, these two fishery types were practiced in the bay. Later on, conflicts emerged ostensibly due to excess trawl bycatches otherwise targeted by artisanal fishers, perceived environmantal degradation, and damage of artisanal fishing gear by the trawlers. Retained trawler bycatches also flooded the local fish markets with cheap fish that competed unfairly with fish sold by the artisanal fishers. These problems persisted for sometime until a ban on bottom trawling was imposed in September 2006 to pave the way for the formulation of the existing shrimp fishery management plan, six years after the ban. This Ph.D. study therefore, drew its motivation to investigate the status of the Malindi-Ungwana Bay fisheries before and after the trawling ban and fulfilled the following specific objectives:

i. the study determined the trends of the Malindi-Ungwana Bay artisanal fisheries and the semi-industrial bottom trawl landings before and after the trawl ban;
ii. the study characterised the artisanal fisheries in terms of vessel-gear categories and catch composition, and proposed several management recommendations;
iii. the study determined the spatio-temporal distribution patterns and composition of stocks (shrimps and bycatch of finfish species) before lifting of the trawling ban;
iv. the study determined artisanal fishers' perceptions on shrimp trawling activity and identified to what extent fishing activity contributed to the livelihoods of the artisanal fishers.

While the broader framework and key features of this Ph.D. study are explained and introduced in **Chapter 1**, the general discussion and conclusions generated in this entire study, and recommendations for sustainability of the Malindi-Ungwana Bay fisheries, like

other fisheries in the tropics are provided in **Chapter 7**. Therefore, the above fulfilled specific objectives involved: a retrospective analysis of the existing artisanal and trawl data before and after the ban, shore-based artisanal catch assessments after the trawl ban, experimental bottom trawl surveys to determine the status of shrimp stocks and finfish bycatches after the ban, and a socio-economic assessment of artisanal fishers' alternative livelihoods and their perceptions of shrimp trawling in the bay after the trawl ban was lifted in July 2011.

Results in **Chapter 2** are therefore based on aggregated catch data from the Kenya Fisheries Department. The artisanal landings (catches) declined before the ban, but rapidly recovered within 2 years after the ban was imposed. However, shrimp landings in the artisanal fishery were already low before and after the ban. Commercial shrimp landings gradually declined before the ban from 550 t in 2001 to 250 t in 2006, and the shrimp/fish bycatch ratio was 1:1.5 compared to values in early reports of 1:7 in 1999. Before the ban, distinct artisanal catch composition was evident between Formosa/Tana and Malindi/Sabaki areas. This difference was attributed to more abundant freshwater fish families Claridae, Cichlidae and Protopteridae in Formosa, and more abundant marine fish groups of mixed pelagics and mixed demersals, and the families Carangidae, Siganidae, Carcharhinidae and Lethrinidae in Malindi.

Chapter 3 described the artisanal finfish catch composition (total number of species caught, sizes and trophic levels), and catch-per-unit-effort (CPUE) for each of the most popular vessel-gear categories used in the bay. This was based on the fact that specific vessel-gear category combinations instead of the traditional gear-based approach, offers a better alternative for monitoring catches and thus supporting fisheries management. A total of 4,269 finfish belonging to 178 species and 66 families were sampled by the 5 most popular vessel-gear categories between 2009 and 2011. Significant differences in species composition existed between the different vessel-gear categories with highest number of species caught by the canoe-gillnets and lowest number by the foot-handline category. The CPUE was not significantly different between vessel-gear, although this was on the average highest for canoe-gillnet and *mashua*-gillnet, and lowest for foot-handline. The highest trophic level of 4.0 was recorded for the *mashua*-gillnet and the lowest of 3.4 and 3.2 for canoe-gillnet and foot-seine net respectively. This study, singled out the *mashua*-gillnet, canoe-gillnet and foot-seine net as most suitable units for monitoring the artisanal fisheries in Malindi-Ungwana Bay by virtue of landing highest mean trophic level and largest sized individuals for the *mashua*-gillnet, highest number of species caught for the canoe-gillnet, and smallest sized individuals for the foot-seine net.

Shallow water experimental trawl surveys in **Chapter 4** indicated distinct species composition and abundance patterns between the Tana and Sabaki estuaries, attributed mainly to depth, turbidity and season. *Penaeus semisulcatus* was more abundant at the Sabaki area, where it was deeper with a muddy bottom and less turbid waters. *Fenneropenaeus indicus* was more abundant in the Tana area, a shallower, more turbid area with sandy-mud sediments. *Penaeus monodon, Penaeus japonicus* and *Metapenaeus monoceros* were found in both areas, suggesting wider tolerance to environmental conditions. Shrimp total biomass and catch rates were significantly greater during the wet Southeast Monsoon (SEM) season, and decreased with increasing depth. Small-sized *M. monoceros* and *P. monodon* individuals were abundant during the SEM season, whereas large ones with ripe and spent gonads were more common during the dry Northeast Monsoon (NEM) season. Seasonal patterns in gonad maturity were less clear for *F. indicus* and *P. semisulcatus*. The length at first maturity (L_{50}) varied among species, suggesting that different species in the bay started spawning at different sizes, an important biological reference for sustainable resource exploitation.

The same experimental trawl surveys in **Chapter 5** indicated that the associated finfish bycatch rates and biomass were significantly higher in inshore than offshore and distinct in composition, while less pronounced differences were found between seasons. The Shannon-Wiener diversity index was significantly higher during the SEM season, but no differences were found between areas, nor was their a significant interaction effect. A total of 158 fish species in 61 families were identified during the NEM survey, and 161 species in 57 families during the SEM. However, only 7 families contributed for 66.6% by mass during the NEM whereas 10 families contributed for 59.7% during the SEM. Offshore trawl bycatches showed lower similarity with the composition of artisanal catches than inshore trawl bycatches. The similarity between inshore trawl bycatches and artisanal catches was mainly attributed to 7 common and most abundant artisanal target species confirming a localised inshore resource overlap. Whereas these 7 species were mostly absent in offshore trawl bycatches. Furthermore, significantly smaller sized individuals of these 7 species occurred in the trawl bycatches posing a potential risk for low recruitment with continued trawling. Also species diversity in both inshore and offshore trawl bycatches was significantly higher than in artisanal catches further confirming the possible resource overlap between the two fishery types in the Malindi-Ungwana Bay.

The socio-economic study using questionnaires in semi-structured interviews of 151 artisanal fishers in **Chapter 6** indicated that livelihood diversification in Malindi-Ungwana Bay was common. However, full time fishers were associated with relatively higher daily catches and incomes compared to fishers with additional livelihoods. Analysis of economic viability of the different artisanal fishing categories using the Net Present Value (NPV) was found to increase when artisanal fishers additionally undertook either fish trading and micro-business, part time paid-up jobs, or used acquired skills for making extra income. Economic viability was however, low when fishing was undertaken with subsistence farming or when full time fishing was undertaken alone. The majority of artisanal fishers from all fishing categories except those who engaged in part time paid-up jobs perceived a negative impact of shrimp trawling mostly due to its associated damage to artisanal fishing gear, fish habitat, and excessive bycatches that are otherwise targeted by the artisanal fishers. The main conclusions of this Ph.D. study are:

- Bottom shrimp trawling in the bay before the September 2006 ban indicated some negative impact on the artisanal catches, and the target shrimp catches but not on artisanal shrimp catches.
- The *mashua*-gillnet, canoe-gillnet and foot-seine net are suitable fishing units for monitoring the artisanal fisheries in Malindi-Ungwana Bay by virtue of landing highest mean trophic level and largest sized individuals for the *mashua*-gillnet, and highest number of fish species caught for the canoe-gillnet, and smallest sized individuals for the foot-seine net.
- Shrimp catch rates and biomass in Malindi-Ungwana Bay, decreased with increase in depth and away from the shore, and were significantly higher during the wet Southeast Monsoon (SEM) season than the dry Northeast Monsoon (NEM). Also the Tana and Sabaki estuaries significantly differed in shrimp composition, with the shallower and more turbid Tana estuary characterised by more abundant *Fenneropenaeus indicus* and the deeper and and less turbid Sabaki estuary characterised by more abundant *Penaeus semisulcatus*.
- The length at first maturity (L_{50}) was determined for *Fenneropenaeus indicus* (37.4 mm), *Penaeus monodon* (41.9 mm), *Metapenaeus monoceros* (36.0 mm) and *Penaeus semisulcatus* (33.4 mm) as a biological indicator for monitoring.
- The finfish species: *Galeichthys feliceps, Pellona ditchela, Johnius amblycephalus, Leiognathus equulus, Pomadasys maculatus, Otolithes ruber* and *Lobotes surinamensis* were more abundant both in artisanal and trawl bycatches and therefore,

the potential species for resource overlap and conflict between bottom trawling and the artisanal fishery in the inshore area of the Malindi-Ungwana Bay.

- The economic viability of artisanal fishing increased with additional livelihood sources such as fish trading and micro-business, part time paid-up jobs, and use of acquired skills for making extra income, but not with subsistence farming or when full time fishing was undertaken alone.
- Majority of artisanal fishers from all fishing categories except those who engaged in part time paid-up jobs perceived a negative impact of shrimp trawling mostly due to its associated damage to artisanal fishing gear, fish habitat, and excessive bycatches that are otherwise targeted by artisanal fishers.

Samenvatting

Deze doctoraatsstudie behandelde verschillende ecologische en sociaal-economische aspecten van de artisanale visserij en de semi-industriële bodemvisserij op garnalen in de baai van Malindi-Ungwana, Kenia, en dit zowel voor als na de ban op het gebruik van bodemsleepnetten. Gedurende tientallen jaren werden deze twee soorten visserij beoefend in de baai. Na verloop van tijd echter onstonden conflicten die ondermeer in verband werden gebracht met de hoge bijvangsten, bestaande uit soorten ook door artisanale vissers bevist, habitatdegradatie, en beschadiging van de artisanale vistuigen door de semi-industriële vissers. Bijvangsten van de semi-industriële garnalenvisserij belandden ook op de lokale vismarkten, wat resulteerde in goedkope vis die een oneerlijk concurrerentie vormde met vis verkocht door de artisanale vissers. Deze problemen bleven bestaan tot een verbod op sleepnetten in september 2006 werd opgelegd, en aanhef werd gegeven aan de uitwerking van een beheersplan voor garnalenvisserij, nu van kracht zes jaar na het verbod. Dit doctoraatsonderzoek kaderde in deze problematiek en beoogde de status van de visserij in de Baai Malindi-Ungwana te bestuderen vóór en na het verbod op bodemvisserij. De volgende specifieke doelstellingen werden geformuleerd:

v. Het bepalen van de temporale veranderingen in landingen van de artisanale visserij en de semi-industriële landingen vóór, en wat de eerste betreft ook na het sleepverbod;

vi. Het karakteriseren van de artisanale visserij in termen van gecombineerde vaar- en vistuigcategorieën, aan de hand van samenstelling van de vangst, op basis waarvan een aantal aanbevelingen voor verder beheer werden geformuleerd.

vii. Het identificeren van de ruimtelijke en temporele patronen in hoeveelheid en samenstelling van de vangsten (garnalen en bijvangst van vissoorten) vóór het opheffen van het verbod op bodemvisserij;

viii. Het beschrijven van wat de perceptie is van de artisanale vissers op semi-industriële garnalenvisserij, maar ook nagaan in hoeverre visserijactiviteiten bijdragen aan het levensonderhoud van deze vissers.

Terwijl het breder kader en de belangrijkste doelstellingen van deze doctoraatststudie worden toegelicht en geïntroduceerd in **hoofdstuk 1,** worden de algemene bevindingen en conclusies die uit deze studie voortkomen, alsook de aanbevelingen voor een duurzame visserij in de Baai van Malindi -Ungwana, behandeld in **hoofdstuk 7**. Om de eerder opgelijste specifieke doelstellingen te behalen werd ondermeer een retrospectieve analyse van de beschikbare artisanale en sleepnetgegevens vóór en na het verbod uitgevoerd, en de landingen van artisanale vangsten na het verbod op bodemsleepnetten als ook experimentele bodemvangsten geanalyseerd. Op die manier werd niet alleen de status van de garnalenbestanden en de vis bijvangsten bepaald na het ingestelde verbod in 2006, ook werd een socio-economische evaluatie uitgevoerd van de artisanale vissers' alternatieve middelen van bestaan en hun perceptie van garnalenvisserij in de baai nadat het sleepnetverbod opnieuw werd opgeheven in juli 2011.

Resultaten beschreven in **hoofdstuk 2** zijn gebaseerd op vangstgegevens afkomstig van de 'Kenya Fisheries Department'. De artisanale landingen (vangsten) vertoonden een dalende trend net voordat het verbod werd ingesteld, maar herstelde snel binnen 2 jaar na het verbod. Echter, de hoeveelheid garnalen aangevoerd in de artisanale visserij was al laag zowel vóór als na het verbod. Commerciële garnalenlandingen namen geleidelijk af in de tijd van 550 t in 2001 tot 250 ton in 2006. De garnalen / vis bijvangst ratio bedroeg 1:1.5, terwijl vroegere rapporten een ratio vermelden van 1:7 in 1999 . Voordat het verbod werd ingesteld, bestonden uitgesproken verschillen in de samenstelling van artisanale vangsten tussen de regio's Formosa / Tana en Malindi / Sabaki. Dit verschil werd toegeschreven aan de talrijke zoetwatervisfamilies zoals Claridae, Cichlidae en Protopteridae in Formosa, en de meer abundante mariene visfamilies waaronder Carangidae, Siganidae, Carcharhinidae en Lethrinidae in Malindi.

Hoofdstuk 3 beschrijft de artisanale visvangstcompositie (totaal aantal gevangen soorten, lengtedistributies en trofische niveaus), en de vangst-per-eenheid-inspanning (CPUE) voor elk van de meest populaire categorieën vaar-en vistuig gebruikt in de baai. Dit was gebaseerd op het feit dat de gecombineerde vis-en vaartuig categoriën in plaats van de traditionele vistuigcategorieën een beter alternatief boden om de vangsten op te volgen en dus het visserijbeheer te ondersteunen. Een totaal van 4269 vissen behorend tot 178 soorten en 66 families werd geland door de 5 meest populaire vis-vaartuigcategorieën tussen 2009 en 2011. Significante verschillen in soortensamenstelling bestonden tussen de verschillende categorieën met het hoogste aantal soorten gevangen in de groep van kano-kieuwnet-en het laagste aantal soorten door vissers die te voet een handlijn hanteren. De CPUE was niet significant verschillend tussen vis-vaartuig categorieën, maar gemiddeld waren de waarden het hoogste voor kano-kieuwnetten en mashua-kieuwnetten, en het laagst voor de handlijn gehanteerd te voet. Het hoogste trofische niveau van 4.0 werd gevonden voor de mashua-kieuwnet vangsten en het laagste van 3.4 en 3.2 voor respectievelijk kano-kieuwnetten en zegennetten die te voet werden gebruikt. Deze studie toonde aan dat de mashua-kieuwnetten, kano-kieuwnetten en te voet gebruikte-zegennetten als categorieën het meest geschikt zijn voor verdere opvolging in het kader van het toezicht op de artisanale visserij in Malindi-Ungwana Baai, omdat deze categorieën het hoogste gemiddelde trofisch niveau en de grootste individuen landen althans voor de mashua-kieuwnetten, terwijl het hoogst aantal soorten wordt gevangen door de kano-kieuwnetten en het kleinste formaat van vissen door vissers die te voet zegennetten hanteren.

Analyse van de soortensamenstelling van de garnalenvangsten op basis van experimentele staalnamecampagnes uitgevoerd met een semi-industriële sleper in de baai (**hoofdstuk 4**) toonde verschillende soortensamenstelling en abundantiepatronen in de respectievelijk kustgebieden ter hoogte van de Tana en Sabaki estuaria. Deze verschillen werden vooral toegeschreven aan diepte, turbiditeit en seizoenale verschillen. *Penaeus semisulcatus* was meer overvloedig aanwezig ter hoogte van het Sabaki kustgebied, waar het dieper is met een slibrijke bodem en minder turbiede wateren. *Fenneropenaeus indicus* was meer overvloedig aanwezig in het Tana gebied, een ondieper, meer troebel gebied met zandige slibsedimenten. *Penaeus monodon, Penaeus japonicus* en *Metapenaeus monoceros* werden gevonden in beide gebieden, wat suggereert dat deze soorten een bredere tolerantie vertonen voor verschillende milieu-omstandigheden. De totale biomassa en de vangst ratio's waren significant hoger tijdens de meer vochtige Zuidoost Monsoon (SEM) seizoen, en nam af met toenemende diepte. Kleine *M. monoceros* en *P. monodon* individuen waren meer talrijk tijdens het SEM seizoen, terwijl grote individuen met ontwikkelde geslachtsorganen vaker voorkwamen tijdens het droge noordoosten Monsoon (NEM) seizoen. Seizoenale patronen in gonade ontwikkeling waren minder duidelijk voor *F. indicus* en *P. semisulcatus*. De lengte bij de eerste maturiteitsstadia (L_{50}) varieerde tussen soorten, wat erop wijst dat verschillende soorten in de baai beginnen paaien op verschillende groottes, een belangrijke biologische referentie voor de exploitatie van duurzame voedselbronnen.

Dezelfde experimentele staalnames werden in **hoofdstuk 5** geanalyseerd voor bijvangstsamenstelling. Vangst ratio's en biomassa waren significant hoger dichter bij de kust dan meer offshore-en verschilden in samenstelling. Minder uitgesproken verschillen werden gevonden tussen de seizoenen. De Shannon-Wiener diversiteit index was significant hoger tijdens het SEM seizoen, maar geen verschillen werden gevonden tussen de gebieden, noch was er een significant interactie-effect tussen seizoen en locaties. Een totaal van 158 vissoorten in 61 families werd geteld tijdens de NEM campagne, en 161 soorten in 57 families werden gevonden tijdens de SEM staalname. Echter, slechts 7 visfamilies zijn verantwoordelijk voor 66.6% van de biomassa tijdens de NEM, terwijl 10 families 59.7% van de vangst vertegenwoordigden tijdens de SEM. 'Offshore' bijvangsten vertoonden een lagere gelijkenis met de samenstelling van de artisanale vangsten dan de 'inshore' bijvangst. De overlap tussen 'inshore' bijvangsten en artisanale vangst werd hoofdzakelijk toegeschreven aan 7 veel voorkomende artisanale doelsoorten in de semi-industriële bijvangsten. Deze 7 soorten waren meestal afwezig in 'offshore' bijvangsten. Bovendien werden beduidend kleinere individuen van deze 7 soorten in de sleepnetbijvangsten waargenomen, wat een potentieel risico inhoudt voor verminderde rekrutering in geval dat de sleepnetvisserij zich verder ontwikkelt. Ook de soortenrijkdom in zowel 'inshore' als 'offshore' bijvangsten was significant hoger dan in de artisanale vangsten, wat een verdere bevestiging is van de mogelijke overlap tussen beide types visserij in de baai van Malindi-Ungwana.

Een socio-economische studie op basis van van vragenlijsten in semi-gestructureerde interviews van 151 artisanale vissers in **hoofdstuk 6** toonde aan dat er een diversificatie van bestaansmiddelen aanwezig was in Malindi-Ungwana Baai. Voltijdse vissers werden geassocieerd met hogere dagelijkse vangsten en inkomens in vergelijking met de vissers die alternatieve middelen van bestaan combineerden. Analyse van de economische levensvatbaarheid van de verschillende artisanale visserijcategorieën op basis van de netto contante waarde (NCW) bleek te stijgen bij artisanale vissers met bijkomende activiteiten zoals vishandel en 'micro-business', 'parttime' banen, of het gebruik van verworven vaardigheden voor het genereren van een extra inkomen. Economische levensvatbaarheid was echter laag bij de visserij die werd ondernomen in combinatie met zelfvoorzienende landbouw of als full-time visser. De meerderheid van de artisanale vissers uit alle categorieën van visserij behalve degenen die betrokken zijn bij deeltijds betaalde banen ondervonden een negatieve impact van garnalenvisserij vooral te wijten aan de bijbehorende schade aan ambachtelijke vistuig, vishabitat, en excessieve bijvangsten die anders het doelwit zijn van de artisanale vissers.

De belangrijkste conclusies van dit doctoraat zijn :

- Semi-industriële sleepnetvisserij gericht op garnalen in de baai vertoonde tekenen , van een negatieve impact op de artisanale vangsten, maar niet op de garnalenvangst voor het verbod van september 2006.
- De mashua - kieuwnet , kano - kieuwnet en te voet gehanteerde- zegennet zijn geschikte visserij -categorieën voor het toezicht op de artisanale visserij in Malindi - Ungwana Baai op grond van de hoogste gemiddelde trofisch niveau's en de grootste individuen voor de mashua – kieuwnetten, het hoogste aantal vissoorten die worden gevangen door de kano – kieuwnetten, en het kleinste formaat individuen gevangen met een te voet gehanteerde zegennet.
- Garnalen vangstratio's en biomassa in Malindi - Ungwana Baai nemen af met toenemende diepte en afstand van de kust , en waren significant hoger tijdens het vochtige Zuidoost Monsoon (SEM) seizoen dan tijdens de droge noordoosten Monsoon (NEM) . Ook de regio's ter hoogte van de Tana en Sabaki estuaria verschilden significant in garnalensamenstelling , met de meer ondiepe en turbiede Tana regio gekarakteriseerd door hogere aantallen van *Fenneropenaeus indicus,* en de diepere en en minder troebele Sabaki regio gekarakteriseerd door meer *Penaeus semisulcatus* .
- De lengte bij de eerste maturiteit (L_{50}) werd bepaald voor *Fenneropenaeus indicus* (37.4 mm), *Penaeus monodon* (41.9 mm), *Metapenaeus monoceros* (36.0 mm) en *Penaeus semisulcatus* (33.4 mm) en bleek een biologische indicator voor monitoring
- De vissoorten: *Galeichthys feliceps, Pellona ditchela, Johnius amblycephalus, Leiognathus equulus, Pomadasys maculatus, Otolithes ruber* en *Lobotes surinamensis*

waren talrijk zowel in artisanale vangsten als in de semi-industriële bijvangsten en dus potentiële soorten die conflicten tussen beide types visserij in de kustwateren van de Malindi - Ungwana Baai kunnen veroorzaken.

- De economische levensvatbaarheid van de ambachtelijke visserij nam toe indien extra bronnen voor levensonderhoud zoals vis handels-en micro -business , parttime bataalde banen , en het gebruik van verworven vaardigheden aanwezig waren, maar niet met zelfvoorzienende landbouw of indien voltijdse visserij werd ondernomen.
- De meerderheid van de ambachtelijke vissers uit alle categorieën van visserij behalve degenen die betrokken zijn bij deeltijd betaalde banen ondervonden een negatieve impact van garnalen bodemvisserij vooral te wijten aan de bijbehorende schade aan ambachtelijke vistuig , vis habitat, en excessieve bijvangsten van soorten die anders het doelwit zijn van artisanale vissers.

Table of contents

List of acronyms

NEM	Northeast Monsoon
SEM	Southeast Monsoon
WWF	Wildwide Fund for Nature
EACC	East African Coastal Current
SC	Somali Current
WIO	Western Indian Ocean
ESP	Economic Stimulus Program
GRT	Gross Registered Tonnage
EEZ	Economic Exclusive Zone
IUU	Illegal, Unreported and Unregulated
BMU	Beach Management Unit
EAF	Ecosystem Approach to Fisheries
CPUE	Catch Per Unit Effort
nm	Nautical Mile
TED	Turtle Excluder Device
BRD	Bycatch Reduction Device
NPV	Net Present Value

Chapter 1

1. General introduction and background information

1.1 The Kenyan coastal ecosystems

The Kenyan coast runs in a south-westerly direction from the border with Somalia in the north at 1^0 41'S to 4^0 40'S at the border with Tanzania in the south. It lies in the hot tropical region where the weather is influenced by the monsoon winds of the Indian Ocean. Climate and weather systems are dominated by the large scale pressure systems of the Western Indian Ocean (WIO) and two monsoon seasons, the dry Northeast Monsoon (NEM) from October to March and the wet Southeast Monsoon (SEM) from April to September (McClanahan, 1988). Kenya's coastal ecosystems oocupy the western extremity of the tropical Indo-Pacific biogeographic region, and have been classified as part of the Coral Coast of the East African Marine Ecoregion (WWF, 2004). Broadly, the coastal ecosystems are classified into tropical rainforests, estuarine and nearshore areas, and the open sea (Government of Kenya, 2008a). Specifically these ecosystems include: mangrove swamps, coral reefs, seagrass beds, rocky shores, estuaries, beaches, mudflats, sand dunes and terrestrial habitats, and all are closely interlinked. These linkages ensure ecological exchanges among different ecosystems through various biotic and abiotic fluxes. A wide variety of fish and other marine organisms migrate between ecosystems for breeding, feeding and seeking for refugia. An almost continuous fringing reef dominates the inshore areas along the Kenyan coast, except in the Malindi-Ungwana Bay where the river systems have created conditions of low salinity and high turbidity especially during the wet SEM season, which have limited the growth of corals. The distribution of coastal ecosystems is also influenced by the coastal geology and oceanography. The interactions between the north-flowing East African Coastal Current (EACC) and the seasonal south-flowing Somali Current (SC) create a temperature gradient of warm to cool from south to north. This affects the productivity of the open sea ecosystems, resulting in the development of coral reefs in the cooler, nutrient-rich waters of the north, and extensive mangrove, seagrass and suspension-feeding communities towards the south. The rich biodiverse coastal ecosystems provide critical socio-economic and ecological services such as protection from storm surges, food, wood fuel, and livelihoods for the local communities. For instance, the lower Sabaki and Tana River flood plains and oxbow lakes support subsistence fisheries of brackish and freshwater species mainly Protopteridae (lungfishes), Claridae (catfishes), Cichlidae (tilapines), Anguillidae (eels), and prawns (*Macrobrachium* sp). These vital coastal ecosystems are on the other hand, facing serious threats from ever increasing human pressure through tourism, industrial pollution, inshore overfishing, mangrove logging (Tychsen, 2006)., commercial salt production and the upcoming offshore gas and oil exploration (pers. obs.).

1.2 The study area: Malindi-Ungwana Bay

The Malindi-Ungwana Bay comprises of the larger northward Ungwana Bay and the smaller southward Malindi Bay, and lies off the East African coast in the Western Indian Ocean (WIO) region (Fig. 1). The bay is located between the latitudes 2° 30'S and 3° 30'S, and the longitudes 40° 00'E and 41° 00'E and extends from Malindi through Ras Ngomeni in the south to Ras Shaka in the north covering about 200 km long. It encompasses the fishing grounds of Sabaki and Tana river estuaries. Administratively, the Malindi-Ungwana Bay is located within the two counties of Malindi and Tana Delta with populations of 281,552 and 180,901 respectively out of a population of about 3 million for the entire coastal area, about 8 % of the Kenyan population (Government of Kenya, 1999). The bay including the North Kenya Bank covers a total trawlable area of 10,994 km^2 against a total estimate of 19,120 km^2 of the entire Kenyan inshore and offshore areas (Mutagyera, 1984). The bay around the Tana outflow is shallow with a area measuring between 8 and 32 nm. The mean depth at spring high tide is 12 m at 1.5 nm, and 18 m at 6.0 nm from the shore. The depth increases rapidly to

100 m after 7 nm from the shore. Near the Sabaki outflow, the offshore distance stretches between 3 and 5 nm, whereafter depth rapidly increases to 40 m (Kitheka et al., 2005). Critical habitats along the Malindi-Ungwana Bay include mangrove forests, patchy reefs, islets, sandy shores and tidal flats. The Sabaki estuary is an Important Bird Area (IBA) as it hosts large visiting flocks of Madagascar pratincole, and also important resting, roosting and feeding ground for gulls and terns (Tychsen, 2006).

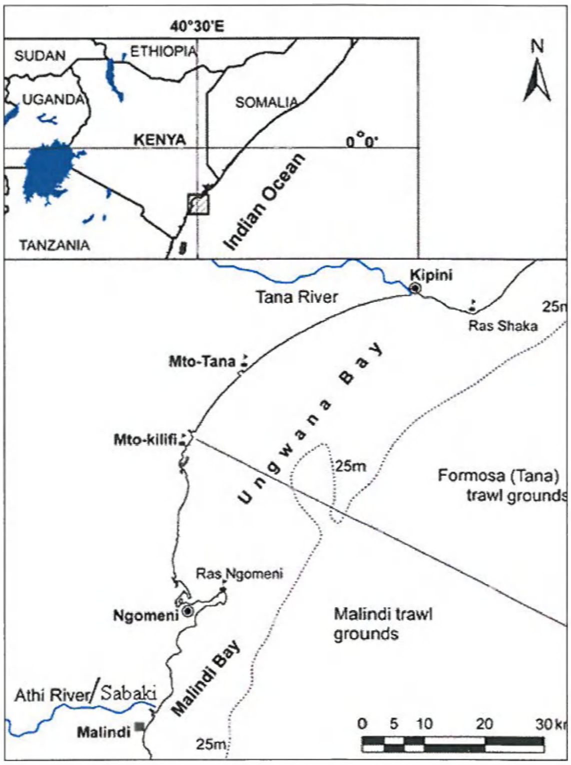

Figure 1. Map of the East African coast showing location of Malindi-Ungwana Bay, Kenya, and Sabaki/Athi and Tana rivers (Munga et al., 2012a).

The Malindi-Ungwana Bay experiences a tropical humid climate, with two distinct seasons, the Northeast Monsoon (NEM) and the Southeast Monsoon (SEM) (McClanahan, 1988). The SEM season (October to March) is characterised by cloudy skies, rains, strong winds and decreased temperatures making the sea rough, and artisanal fishing is minimised during this season. Weather conditions are however, reversed during the NEM season (April to September). The mean annual rainfall experienced in the bay is 900 mm and over 1,016 mm in the wetter areas south of Malindi with a comparatively high relative humidity all year round, reaching its peak during the wet months of April to July. The average amount of daily sunshine is 7.3 h in July and 9.3 h in December (Kitheka, 2002; Tychsen, 2006).

1.3 The importance of artisanal fisheries

Artisanal fishing is defined as small-scale traditional fishing carried out for subsistence or commercial purposes in which the owner is directly involved in the daily running of the enterprise and relatively small amounts of capital are used (Government of Kenya, 2012). Artisanal or small scale fisheries are important socially, nutritionally and economically especially in the developing tropical countries (Mangi et al., 2007; Davies et al., 2009). About 95% of the world's fishing population and over 60% of the world's marine fisheries resources come from the developing countries where artisanal fisheries account for 25% of the world catch and half of the fish used for direct human consumption (Mathew, 2001). Over the past two decades, artisanal fisheries have grown significantly and their rapid expansion under open access regime exerts overfishing pressure on the coastal and marine resources (Mathew, 2001). Over-exploitation coupled with the current climate change phenomenon are the principal threats posing challenge to the management of especially reef-based fisheries (McClanahan, 2002; Cinner et al., 2009).

In Kenya, fish is an important source of animal protein to the local communities both inland and coastal. The fisheries sector comprises of three sub-sectors: inland fisheries, coastal and marine fisheries, and aquaculture together contributing 0.5% of the Gross Domestic Product (GDP) with the highest of 24% contributed by agriculture and forestry (Kenya Bureau of Statistics, 2012). The inland fisheries from lakes, rivers and dams account for 85% of the national fish production, followed by aquaculture (9%), and coastal and marine fisheries with 6% (Government of Kenya, 2010a). About 8,000 t of coastal and marine fisheries landings valued at US$ 4.1 million are landed annually (Government of Kenya, 2010a; Fig. 2) by 13,706 artisanal fishers using a total of 3,090 fishing crafts in 160 fish landing sites (Government of Kenya, 2012) along the 640 km coastline. Over the past 3 years since 2009, the increase on fisheries production has been focussed on development of aquaculture through the Economic Stimulus Program (ESP) towards attaining long term solutions to the challenges of food security in fulfilling the Vision 2030 blue print. As a result overall fisheries production growth rate increased to 3.1% in 2011 from 2.7% in 2010 (Kenya Bureau of Statistics, 2012) attributed to increased fish yields from aquaculture. The coastal and marine artisanal fisheries landings, described as multispecies consist of 5 main broad taxa *viz.* demersals (bottom dwelling species), pelagics (surface dwelling species), elasmobranchs (sharks and rays), molluscs (oysters, squids, *beche-de-mer* and octopus), and crustaceans (shrimps or prawns, lobsters and crabs). Total annual landings are dominated by demersals (50%) followed by pelagics (28%), with molluscs, crustaceans and elasmobranchs contributing the remaining least (22%) (Government of Kenya, 2010a; Fig. 3). In this study, the word shrimp is used interchangeably with prawn to mean the same group of decapod species mostly targeted by the semi-industrial bottom trawling.

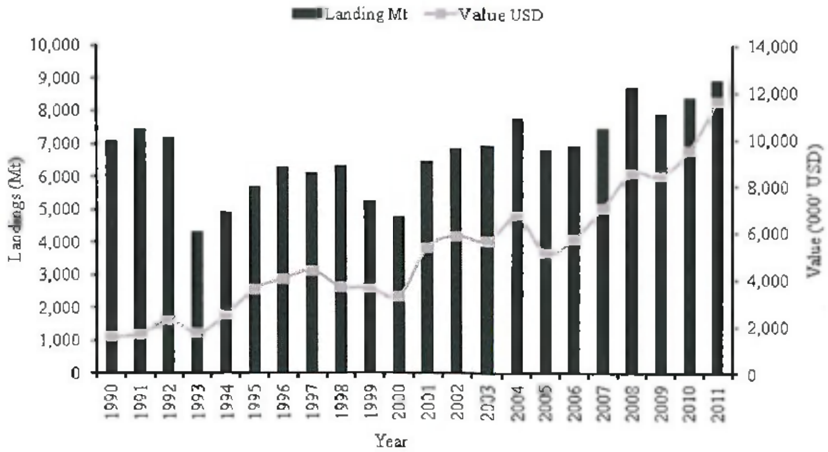

Figure 2. Trends in coastal artisanal fisheries production in Kenya by quantity and value from 1999-2011 (1 USD = 86.6 KES by February 2013) (compiled from annual fish landings statistics, Kenya Fisheries Department).

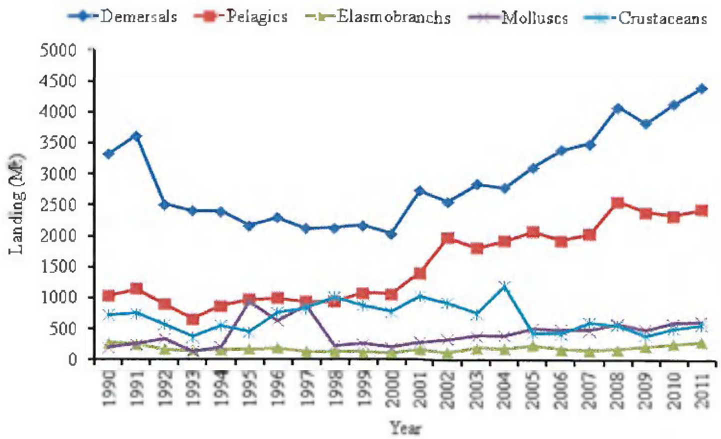

Figure 3. Trends in coastal artisanal fisheries production in Kenya by main taxa landed by quantity from 1990 - 2011 (compiled from annual fish landings statistics, Kenya Fisheries Department).

1.4. Fishing gear, vessels and fishing grounds

A variety of artisanal fishing gear and vessels are associated with the artisanal fishery in Kenya, like in many other tropical and developing countries. The fishing gear are of two categories, traditional and modern. Traditional fishing gear (Fig. 4) include basket trap (*malema*), fence trap (weirs), spear guns, harpoons and use of poison (Ochiewo, 2004; Hoorweg et al., 2008). The use of spear guns and poison is illegal and prohibited by law (Government of Kenya, 1991) as they are considered destructive to the environment, however such gear are still in use in certain areas of the Kenyan coast, especially in the south due to lack of enforcement, while a decline in use of such gear has been reported in some fishing grounds of north coast Kenya (Hoorweg et al., 2008). Traditional fishing gear are used in relatively shallow fishing grounds: lagoon and inshore areas dominated by coral reefs and seagrass beds targeting demersal species (Fig. 5) mostly Siganidae (rabbitfishes), Scaridae (parrotfishes) and Lethrinidae (emperors) (Hicks and McClanahan, 2012). The traditional fishing gear are simple, locally designed and inexpensive, accessible to many artisanal fishers, making especially reef fisheries vulnerable to overfishing (Mangi et al., 2007).

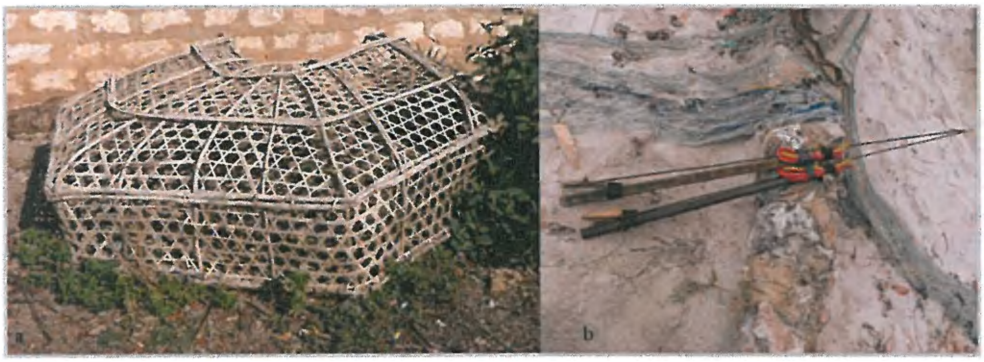

Figure 4. Traditional fishing gear used in the coastal artisanal fishery in Kenya (a) basket trap and (b) spear gun. (Photo credit: C.N. Munga, 2013)

Figure 5. Some of the demersal species targeted by traditional fishing gear in seagrass beds (a) Siganidae and (b) Scaridae. (Photo credit: C.N. Munga, 2013)

The modern artisanal fishing gear (Fig. 6) are more expensive and include a variety of gillnets, seine nets, cast nets, ring nets, and hook and lines (handlines and longlines). Gillnets are operated either passively by setting (set gillnets) or actively by drifting (drift gillnets) by a team of 2 to 5 or more fishermen, held vertically by floats and sinkers in the water column. According to the regulation, the minimum mesh size is 2.5 inch (6.35 cm) (Government of Kenya, 1991). Therefore, all nets with less than 2.5 inch mesh size are illegal by law. Large gillnets and longlines are operated mostly in fishing grounds out of the reef in relatively deep waters targeting mostly sharks and pelagic fish species. Seine nets are mostly used in inshore relatively shallow waters targeting both demersal fish species and shrimps, while ring nets are the most recent modern nets used to target small and medium sized pelagics such as Scombridae and Carangidae in offshore fishing grounds. Despite still in use, beach or pull seines and monofilament nets are illegal by law. In most cases, these nets have smaller mesh size than the recommended and the dragging effect on the seabed during fishing is destructive to the environment. In addition they are landing highest diversity of small sized and juvenile individuals (McClanahan and Mangi, 2004). The monofilament nets are made of non-biodegradable synthetic fibre and are percieved to conduct 'ghost' fishing as they tend to continue fishing when they accidentally get lost in fishing grounds, although the impact of 'ghost' fishing has not been quantified.

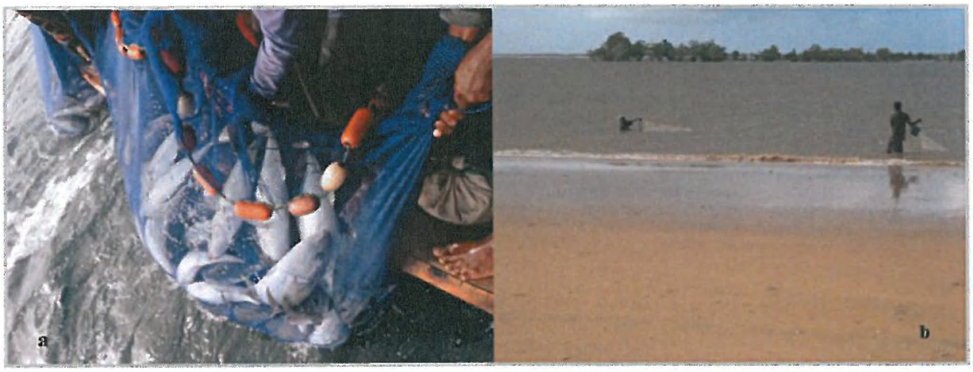

Figure 6. Some of the modern fishing gear used in the Kenyan artisanal fishery (a) ring net and (b) prawn seine. (Photo credit: C.N. Munga, 2010 off the Kipini area north of the Malindi-Ungwana Bay)

Like the fishing gear, vessels or crafts are diverse and some fishers lack crafts altogether using foot to access fishing grounds. Over the years, there has been increasing number of fishing crafts and fishers all over the country (Fig. 7), a sign of increasing pressure on the fisheries resources. The current composition of foot fishers in the artisanal fishery is about 15% (Government of Kenya, 2012). Most of the crafts used are small (about 4 m long) propelled manually by sails, paddles or poles. These artisanal crafts (Fig. 8) include a variety of canoes (*hori* and *dau*). Other slightly bigger crafts are the outrigger boats (*ngalawa*), and *mtori*, but these are relatively few in number. The biggest craft (more than 10 m long) is the *mashua* (plankwood boat pointed at one end) that are used with large gillnets in fishing grounds outside the reef. Most of the *mashua* boats are propelled mostly by outboard engines, and a few by inboard engines.

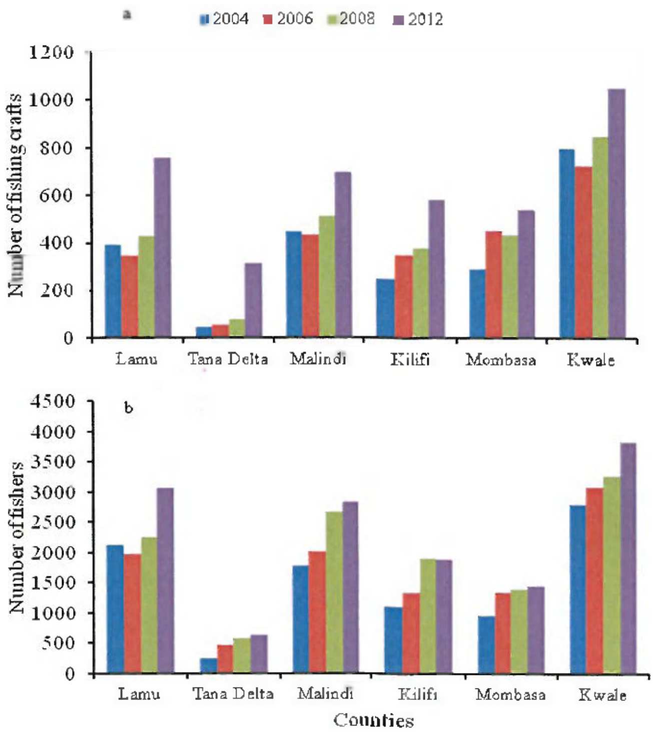

Figure 7. Trends in the number of artisanal fishing effort (a) number of fishing crafts and (b) number of fishers over time by counties along the Kenya coast (Government of Kenya, 2012).

Figure 8. Different types of crafts used in the artisanal fishery in Kenya (a) outrigger, (b,c&d) canoe types, and (e) mashua boat. (Photo credit: S. Ndegwa, 2013)

The species composition in artisanal catches is influenced by a number of factors. These include gear type used, fishing ground or habitat type, fishing intensity, seasons, market availability, the time of fishing whether day time or night time, and duration of fishing. Certain gear types are used to target specific species, but artisanal fishers would retain all catches with discarded bycatch hardly reported (Mangi et al., 2007). For example, large gillnets also called sharknets are used to catch sharks, and prawn seines are used to target prawns or shrimps. The habitat complexity of a fishing ground determines what gear type can be used. Seagrass beds are mostly fished using basket traps targeting mostly herbivorous species: siganids, scarids and lethrinids. Coral reef areas are dominated by corallivorous reef species such as butterflyfishes (chaetodontids) and wrasses (labrids). Differences in fish species composition exists between fishing grounds subjected at varying levels of fishing intensity. A heavily fished area will tend to be dominated by a few fish species and low in trophic level, as fishers tend to have a preference of first removing fish of high trophic level (McClanahan and Mangi, 2004). The low trophic level of artisanal catches in a southern Kenya artisanal reef fishery was a sign of over-fishing as found out in a study by McClanahan and Mangi (2004). Also higher species diversity have been associated with the no-take marine protected areas than with the partially-protected marine areas which are under high fishing pressure (McClanahan and Kaunda-Arara, 1996; Chabanet and Durville, 2005; Munga et al., 2012b).

Seasons affect the distribution and abundance of some fish species, which in turn determine their availability in fishing grounds, and ultimately catch composition. For example, increased abundance of carangids (trevallies) was associated with warm temperatures as found out in two separate studies by Munro et al., (1973) and Munga et al., (2012b), and also a long-term fisheries-independent monitoring programme in the northern Indian River Lagoon of Florida reported higher species diversity during the warmer summer season (Tremain and Adams, 1995). Different species in artisanal catches have different economic value and market availability that affect their level of exploitation. A good example is the sea cucumber and lobster fisheries in Kenya and the Western Indian Ocean (WIO) region at large. Due to the high export market value of these species, many artisanal fishers target them, and as result a decline in catches have been experienced over time due to over exploitation (Kulmiye and Mavuti, 2004; Ochiewo et al., 2010). Day and night times affect trawler catch compositions of especially the penaeid shrimps. For intance, increased catches of *Penaeus semisulcatus* have been reported to be more successful during night trawling, as this species naturally burrows in mud during day time and emerges to feed during the night (Hughes, 1966; Vance et al., 1994; de Freitas, 1986, 2011). Finally, artisanal catches composition and volumes have been reported to vary with use of specific vessel-gear combinations, as found out by Ochiewo, (2004) in a study in the southern artisanal fishery of Kenya.

1.5. The semi-industrial bottom trawl fishery in Kenya

Semi-industrial trawling is defined as mechanised harvesting of shrimps (prawns) using decked vessels not less than 50 Gross Registered Tonnage (GRT) with dragging nets pulled from behind the vessel (Government of Kenya, 2012). The evolution of bottom trawl fishery in the Malindi-Ungwana Bay, Kenya and the associated conflicts with the artisanal fishery have been studied (Fulanda et al., 2011; Munga et al., 2012a). Trawling started from the early 1970s with a fleet of more than 4 private trawlers and the fishery was not fully managed by then until 2004 when some management measures were put in place following research recommendations (KMFRI 2002, unpublished technical report). The semi-industrial bottom trawl targeted the five shallow water penaeid shrimp species found in the bay: *Fenneropenaeus indicus, Penaeus monodon, Metapenaeus monoceros, Penaeus semisulcatus* and *Penaeus japonicus* that contributed 46%, 21%, 20%, 12%, and 1.3% to the overall landing respectively (Mwatha, 2005). The associated discards included juveniles of demersal fish species, lobsters, squids, octopus, sharks, rays and occasionally incidental capture of the endangered sea turtles (Fulanda, 2003; Mwatha, 2005). A detailed description of the trends of the bottom trawling target species and associated bycatch before and after the trawl ban has been discussed in Chapter 2 (Munga et al. 2012a).

In the 1990s, user conflicts in the bay between trawlers and the artisanal fishers became more pronounced due to damage of artisanal gear and reduced artisanal catches (Munga et al., 2012a). In addressing this problem, the Kenya Fisheries Department recommended for onboard retention of all bycatch with commercial value in the trawlers. Later on, a regional remedial action towards shrimp trawl bycatch management in the Western Indian Ocean (WIO) (Fennessy et al., 2004) was undertaken and by September 2006, the Kenya Government further reacted by imposing a ban on the bottom trawling in the bay. By this time the number of trawlers in the bay ranged between 4 and 5 trawlers after several decades of active trawling (Mwatha, 2005).

1.6. Kenya's territorial waters and Exclusive Economic Zone

Kenya's territorial waters extend 12 nm offshore, but only upto 3 nm is utilised by the artisanal fishery. The Exclusive Economic Zone (EEZ) extends 200 nm offshore (approximately 230,000 km^2) with a proposed extension of 150 nm (approximately 103,320 km^2) giving Kenya an EEZ of 350 nm (Government of Kenya, 1991; Government of Kenya, 2009) and a total area of 333,320 km^2, approximately 57.5% of the size of mainland Kenya. Currently Kenya does not have the capacity to exploit fisheries stocks beyond its territorial waters and the EEZ. Instead, Kenya has been licensing a number of foreign industrial fishing vessels to exploit the offshore fisheries resources within its EEZ. These vessels, which vary in number each year (Fig. 9), are long liners mostly from Taiwan and Seychelles, and purse seiners mostly from Spain, Seychelles and France targetting pelagic and highly migratory tuna, tuna-like species and billfishes. Volume of catches are reported in the national fisheries statistics, but high chance of under-reporting catches by these vessels exists due to lack of mechanisms of data verification since Kenya does not have anchoring fish port facilities for such vessels. Cases of Illegal, Unreported and Unregulated (IUU) fishing from other foreign distant fishing nations have been reported within the EEZ due to lack of capacity in Monitoring, Control and Surveillance.

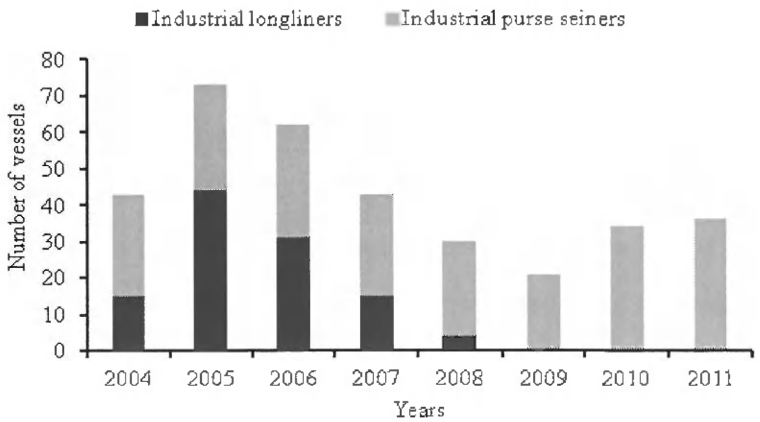

Figure 9. Trends in number of licensed foreign industrial fishing vessels plying the Kenyan EEZ in the recent years (compiled from annual registered foreign vessel statistics, Kenya Fisheries Department).

1.7. Fisheries stock assessment surveys

Historical fisheries stock assessment surveys in Kenya were conducted by the Food and Agriculture Organisation (FAO) of the United Nations. The first survey off Malindi-Ungwana Bay was conducted in 1958 and estimated an annual potential of 5,000 t of fish. This led to a proposed mechanization of inshore fishing crafts and offshore small fishing vessels beyond the reef (Martin, 1973). The first shallow water bottom trawl surveys in the bay were conducted in the early 1960s using local vessels: RV *Shakwe*, RV *Menika* II and RV *Manihine*. Surveys by RV Dr. *Fridtjof Nansen* were conducted between 1980 - 1983 (Mbuga, 1984) at depths of 10–700 m which investigated the abundance and distribution of fish by trawling and by acoustics. Biomass of fish in these surveys was estimated between 18,000-32,000 t for the inshore waters and 10,000 t for the offshore (Mbuga, 1984). The marine fish production potential in the Kenyan EEZ by then was estimated between 150,000–300,000 t/yr (Iversen and Myklevoll, 1984). More localised shallow water bottom trawl surveys have been conducted recently in Malindi-Ungwana Bay just before and after the trawl ban in September 2006 (KMFRI 2002, unpublished technical report; Fisheries Department and Moi University

2006, unpublished technical report; Kimani et al., 2010 unpublished technical report; Kimani et al., 2011 unpublished technical report: Kimani et al., 2012 unpublished technical report). All these shallow water surveys gave indications of stock status and compositions in the bay at different times.

On the other hand, fisheries frame surveys, which are land-based assessments of fishing effort (number of fishers, fishing crafts and gear), and information on fish landing sites and associated infrastructure for the purposes of artisanal fisheries management and decision making were conducted in 2004, 2006, 2008 and 2012. These surveys are coordinated by the Kenya Fisheries Department. Results indicate that the artisanal fisheries sub-sector grew at an average percent of 14.9 ± 1.4 in number of fishers and an average percent of 22.1 ± 12.6 in number of fishing crafts (vessels) between 2004 and 2012 (Government of Kenya, 2012).

1.8. The South West Indian Ocean Fisheries Project (SWIOFP)

The experimental shallow water bottom trawl surveys reported in this thesis were carried out in the framework of the South West Indian Ocean Fisheries Project (SWIOFP). The SWIOFP was a regional research programme (2008-2013) funded by the World Bank and the Global Environment Facility (GEF) that aimed to promote the environmentally and socially sustainable management of fisheries resources, and the preservation of biodiversity of the riparian countries (highlighted in green) situated within the Agulhas and Somali Current Large Marine Ecosystem (ASCLME) (Fig. 10). To address this goal, the project had six components: 1) fisheries data gap analysis, archiving and information technology; 2) assessment and sustainable utilisation of crustacean resources (shrimps, lobsters and crabs); 3) assessment and sustainable utilisation of demersal fishes; 4) assessment and sustainable utilisation of pelagic fishes; 5) mainstreaming biodiversity in national and regional fisheries management; and 6) strengthening national and regional fisheries management. Ship-based surveys were used for data and samples collection.

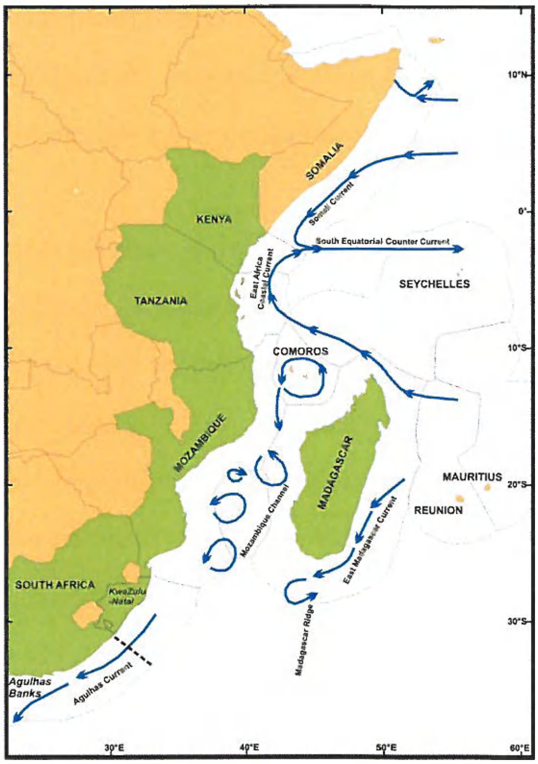

Figure 10. The SWIOFP study area of the riparian countries (in green) within the South West Indian Ocean region and the associated ocean currents and eddies (SWIOFP, 2009).

1.9. Fisheries management and legislation

Fisheries management in the world dates back hundreds of years ago, and this arose due to the threat of fish stock depletion (Kolding and Zwieten, 2011). Fisheries biologists developed stock assessment models in order to understand how fish stocks responded to exploitation. Before the introduction of regulations on mesh and catch sizes to curb the effect of open access, fisheries resources were thought to be infinite (Kolding and Zwieten, 2011). It was common knowledge that man's capacity to harvest was limited (Smith, 1994), and the 'tragedy of the commons' (Hardin, 1968) resulting from overuse of resources and ecological degradation was not perceived. However, this changed with technological advancement and many world fisheries instead showed a declining state due to overfishing (Kolding and Zwieten, 2011). It was evident that regulation on mesh and catch sizes alone was inadequate to provide for rational fisheries exploitation, and instead regulation on fishing effort was finally introduced as an essential element in fisheries management (Caddy, 1999; Halliday and Pinhorn, 2002).

In Kenya, traditional fisheries resources management was community-based that was led by an elder and associated with user-rights (McClanahan et al., 2005). Regulation on fishing gear, fishing time and certain marine areas or sites (closures) were also practiced (McClanahan et al., 1997) just like in conventional fisheries management. Area closures were perceived as holy sites and fishermen feared or respected the spirits associated with such closures, and fishing in these areas was only permitted when in a holy state (see McClanahan et al., 2005). These traditionally restricted marine closures were regarded as traditional form of conservation (McClanahan et al., 1997), and served as the conventional Marine Protected Areas (MPAs) that were introduced in Kenya through legislation in the late 1960s, whose main objective was biodiversity conservation. The traditional form of management was, however, regarded ineffective in protecting species diversity and ecological functions as this was viewed strictly as social self-organisation rather than human-resource organisation, and to some extent poor enforcement (McClanahan, 1997). Currently, the management of artisanal fisheries in Kenya is by co-management approach, which is a more adaptive, and participatory way (Pomeroy and Rivera-Guieb, 2006). Typically, this approach involves the role of fishers, their organisations and communities in fisheries management through a legally established structure known as Beach Management Unit (BMU) with specified legal mandates and areas of operation (Fisheries Beach Management Units Regulations, 2007). This approach has resulted in sharing of decision making among fisheries stakeholders with reduced conflicts between fishers and managers, and hence increased compliance.

The multispecies, multigear and multifleet nature of the artisanal fisheries in Kenya coupled with the open access strategy, like other artisanal fisheries in the tropics is still facing many management challenges. These include the lack of appropriate fisheries stock assessment models to determine stock abundance. The use of Maximum Sustainable Yield (MSY) in artisanal fisheries is inappropriate, as this was developed for temperate fisheries to manage single target species of high biomass rather than the tropical multispecies fisheries targeting many species of low individual biomass (Pauly and Murphy, 1982; Roberts and Polunin, 1993; Mangi et al., 2007). The lack of long term and quality data on artisanal catches and the lack of adequate resources to conduct monitoring have also hampered the management of artisanal fisheries (MacClanahan and Mangi, 2004; Marques-Farias, 2005; Cinner et al., 2009; Kronen et al., 2012). Presently fisheries co-management in Kenya still observes the regulations on fishing gear and effort, mesh and catch sizes, closed areas and seasons that are embedded in the national fisheries legislations (Fisheries Act Cap 378, 1991; Fisheries Beach Management Units Regulations, 2007; Shrimp Fishery Management Plan, 2010; Fisheries Bill, 2012). Most of these regulations are not enforced in addition to use of illegal fishing gear such as beach seines, monofilament gillnets, spear guns, and even the use of poison to harvest fish. These illegal artisanal fishing gear and non-compliance for large vessels like trawlers and foreign vessels in the EEZ are hoped to be controlled through an effective Monitoring Control and Surveillance (MCS) system, implementation of onboard observer program, and the mandatory use of Vessel Monitoring System (VMS) that are provided for in the National Oceans and Fisheries Policy, 2008 and Fisheries Bill, 2012.

The co-management of fisheries resources in Kenya, like other tropical fisheries is now shifting towards the widely accepted ecosystem-based management or Ecosystem Approach to Fisheries (EAF). This means all interactions with the ecosystem are taken into account while managing fisheries, and also considers relevant human dimensions and participatory processes (FAO, 2003; de Young et al., 2008). The EAF attempts to deal with issues in a holistic way, a feature often lacking in the conventional fisheries management practices that focus on individual species or groups of species commonly referred to as 'target resources-oriented management (TROM)'. The EAF operates under two paradigms that are interlinked. These are the 'ecosystem management' that conserves the structure, diversity and functioning of the ecosystems and 'fisheries management' that satisfies the societal and human needs for food and economic benefits (FAO, 2003). A requirement to comply with EAF is the formulation of fisheries management plans. Apart from the already established management plans of Marine Protected Areas, Kenya has just started to formulate other marine fisheries management plans. The Malindi-Ungwana Bay shrimp fishery management plan was completed in 2010 but did not fully follow the EAF guidelines. The plan was formulated without adequate background information and research plan, in addition to lack of a multi-sectoral committee for the plan implementation. The management plan therefore risks not to achieve the EAF principles of maintaining ecosystem integrity, improve human-wellbeing, application of the precautionary approach for adaptive management, full stakeholder participation, and improved research to better understand all the components of the ecosystem. This thesis therefore, forms a fundamental scientific contribution for the revision of the Malindi-Ungwana Bay shrimp fishery management plan.

Apart from the national fisheries legislations embracing the adoption of EAF in Kenya, the principles of EAF are also included in a number of regional and international agreements and conference documents of which Kenya is party of. The Eastern African regional 1985 Nairobi Convention has a protocol on Specially Protected Areas and Wildlife (SPAW) specifically for coastal and marine biodiversity. The 1972 United Nations Conference on Human Environment (Stockholm, Sweden) highlighted concepts central to the ecosystem management in general and to EAF in particular. The 1982 United Nations

Convention of the Law of the Sea (UNCLOS) formulated the basis for the conventional fisheries management and development. The early expression of the concern for the impact of land-based sources of pollution and degradation on fisheries is captured in the FAO Technical Conference on Marine Pollution and its Effects on Living Resources and Fishing (Rome 1970). The FAO Technical Conference on Fishery Management and Development (Vancouver, Canada 1972) calls for new management approaches based on precaution, and addresses the problems of multispecies fisheries. The principles of conservation considered as a precursor of the EAF are embedded in the 1980 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). The World Commission on Environment and Development (WCED, 1984-87) and the resulting Brundtland Report (*Our Common Future*, WCED, 1987) further developed the concept of sustainable development and cooperation on transboundary environmental problems and natural resources.

Other international conferences with relevance to EAF include the 1992 United Nations Conference on Environment and Development and the Agenda 21 (UNCED) that led to the adoption of conventions and agreements embracing EAF, such as the Framework Convention on Climate Change, the Biodiversity Convention and the United Nations Fisheries Stock Agreement (FSA). The Jakarta Mandate on Marine and Coastal Biological Diversity (1995; COP2; Decision II/10) elaborates further on the ecosystem approach adopted by the Convention on Biological Diversity (CBD) focussing on protected areas, the precautionary approach, scientific and indigenous knowledge, and stakeholders' participation. The 1995 FAO Code of Conduct for Responsible Fisheries is the widely recognised and most complete operational reference for fisheries management that combines many aspects of fisheries with environmental conventions and instruments such as the 1995 Kyoto Declaration on the Sustainable Contribution of Fisheries to food Security, and the 2001 Reykjavic Declaration on Responsible Fisheries in the Marine Ecosystem. The application of the ecosystem approach is also the subject of the 1979 Bonn Convention on Migratory Species (CMS) and the 2002 World Summit on Sustainable Development (WSSD, Johannesburg).

1.10. The impact of commercial salt production in Malindi-Ungwana Bay on artisanal fisheries

Large scale production of salt in Kenya is conducted along the Gongoni-Marereni stretch, towards south of the Malindi-Ungwana Bay. The process of salt production involves the clearing of the near shore mangroves and other terrestrial vegetation for excavation of large reservoirs to hold sea water that is eventually channeled to nearby salt pans. Sea water is usually fed in the large reservoirs by tides or by pumping with diesel-powered generators. In the salt pans, sea water evaporates, develop to brine and finally crystallize into salt blocks for harvesting and processing. One of the most directly affected artisanal fisheries by salt production is the mud crab fishery due to loss of some of the mangrove vegetation in the affected areas. Mud crabs are crustaceans of commercial value that utilize mangroves as critical habitat during their life cycle since as adults they feed on benthic invertebrates living in the mangroves (Hill, 1975). As a result low crab catches have been reported in the affected areas (Government of Kenya, 2012).

As sea water is pumped into the reservoir (Fig. 11a) before it is distributed to various salt pans, the water comes in with fingerlings and shrimp larvae thereby stocking the reservoir with fish and shrimps (Fig. 11d). As a result some of the water reservoirs and even abandoned salt pans have formed fishing grounds (Fig. 11b) especially for fishers without fishing crafts. These reservoirs and pans have formed also feeding grounds for piscivorous birds and flamingoes (Fig. 11c). Fishing in these reservoirs and pans is not affected by the open sea tides and winds, and therefore is conducted throughout the year supporting the neighboring local fishing communities. This has the potential to reduce the pressure on artisanal fishery resources in the inshore coastal fishing grounds in the bay. The contribution of fisheries yields from these reservoirs is however, yet to be established.

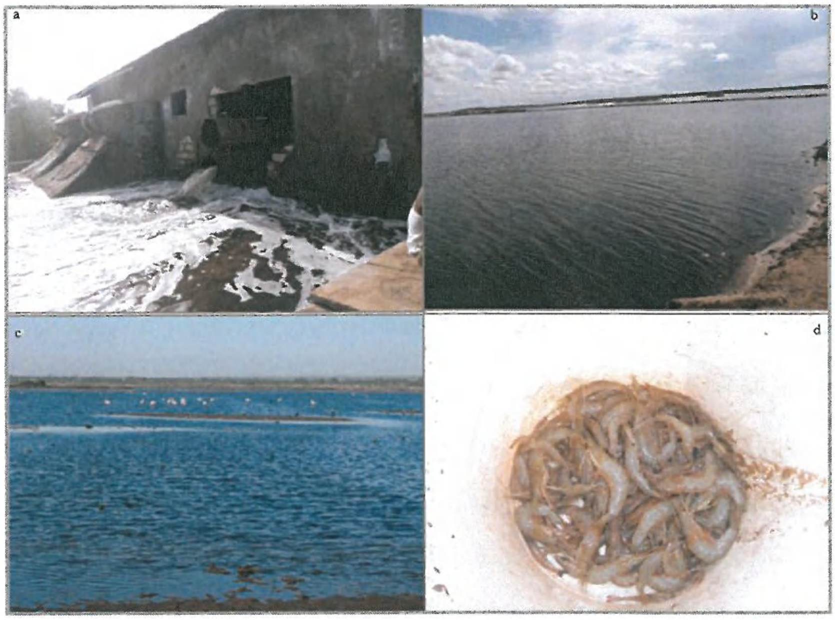

Figure 11. Impact of commercial salt production activity to artisanal fisheries and biodiversity in Malindi-Ungwana Bay, Kenya (a) sea water abstraction into a reservoir, (b) filled reservoir with sea water ready to be fed in salt pans, (c) reservoir as a feeding ground for flamingoes and (d) shrimps harvested by artisanal fishers from the reservoir. (Photo credit: C.N. Munga, 2013 along Marereni area of the Malindi-Ungwana Bay).

1.11. The potential impact of gas and oil drilling offshore the Malindi-Ungwana Bay

A number of multinational oil exploration companies have bidded for at least 8 of the 46 gazzetted offshore gas and oil exploration sites in Kenya. These gazzetted offshore blocks potentially harbour oil and gas since the Kenyan coastline shares the same geological formation with its neighbouring Tanzania where such hydrocarbon deposits have been discovered. Increased activity in oil and gas exploration, especially the recent discovery of oil reserves in inland Turkana County was good economical news for Kenya as the country seeks to reduce its fuel imports. One of the 8 offshore blocks (Block L-08) lies some 43 nm offshore the Malindi-Ungwana Bay (Fig. 12). The identified Exploration Block lies outside the artisanal fishing zone, but a small section of artisanal fishing ground between Malindi and Ngomeni falls within the buffer zone, thereby excluding artisanal fishing. Potential impact of oil contamination is expected in the inshore fishing grounds and nearby ecosystems (Malindi-Watamu National Marine Parks and Reserves, and Kiunga National Marine Reserve) due to the existing currents, wave and tidal effect. Migratory fish species such as the neritic tuna and tuna-like species, offshore spawning of the penaeid shrimp species are among the identified fisheries that could be impacted by this oil and gas exploration activity offshore. So as to manage such expected impact, an environmental and fisheries monitoring programme should be put in place that will include water quality, sediments, primary productivity, finfish and shellfish.

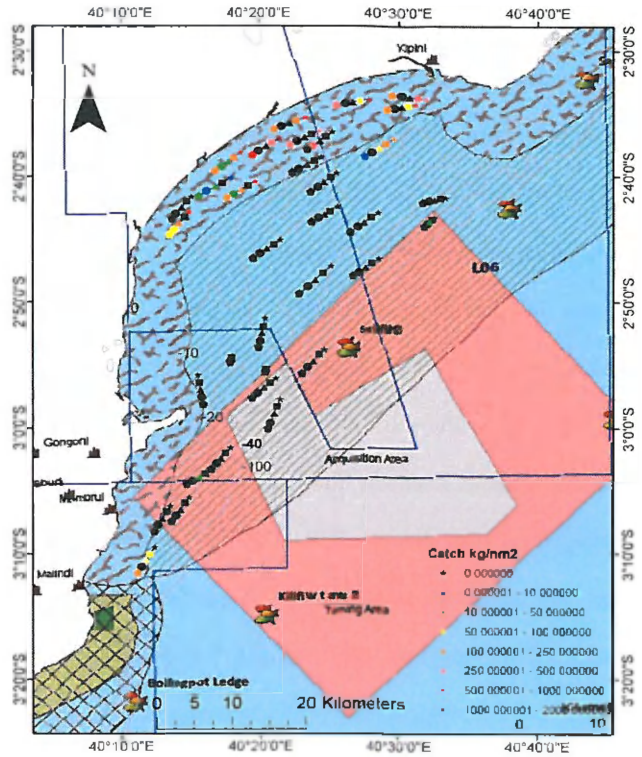

Figure 12. Location of the oil and gas exploration site (Block-L8, grey region) off the Malindi-Ungwana Bay, Kenya in relation to the experimental trawl transects (coloured dots) and inshore artisanal fishing grounds. The region in light red is the buffer zone out of bounds for fishing activity.

1.12. Rationale of the study

The Malindi-Ungwana Bay is one of East Africa's important marine fisheries sustaining both semi-industrial bottom trawling and artisanal fisheries (Fulanda et al., 2011; Munga et al., 2012a). These two types of fisheries by legislation are required to operate in different use zones within the bay, but in practice overlap of fishing grounds has been observed. Initially all fishing grounds within 0-5 nm zone were reserved for the artisanal fishers, and the zone beyong 5 nm reserved for shrimp trawling (Fisheries Act Cap 378, 1991). For many decades, the bay supported both types of fisheries. But due to the arbitrary nature of these use zones and the lack of a management plan before the ban, the trawlers violated the legislation and encroached the artisanal fishing grounds and trawled grounds of less than 3 nm. This resulted in resource use conflict due to damage caused to artisanal gear by the trawlers, and excess discarding of trawl bycatches traditionally targeted by the artisanal fishers (Fulanda, 2003; Mwatha, 2005). This culminated in a six year trawl ban (September 2006– July 2011), and by the time of the ban, both artisanal and bottom trawl catches had decreased in the bay (Munga et al., 2012a, **Chapter 2**).

As the ban was still effective, a stakeholder consultative process formulated the shrimp fishery management plan in 2010. This current regulation revised the use zones in the bay, and now bottom trawling is allowed from 3 nm offshore and beyond. However, this management plan lacks adequate scientific information to guarantee an appropriate ecosystem approach. The management plan did not follow all the Ecosystem Approach to Fisheries (EAF) management plan guidelines especially the **background** of the fishery which did not include a description of the trawling and artisanal fishing activities, resources and the ecosystem, in addition to the ecological issues and challenges. **Evaluation of management** is another EAF guideline that was not observed in the shrimp fishery management plan. The management plan did not include any information on the status of the stocks including bycatch species composition, state of the ecosystem and socio-economic characteristics. To contribute towards this information, experimental bottom trawl surveys were conducted before the ban was lifted and provided indications of the amount of shrimp stocks as well as spatio-temporal patterns (Munga et al., 2013, **Chapter 4**). The trawl surveys also gave an opportunity to study bycatch composition of finfish species, that are otherwise a target for the artisanal fishery (Munga, et al., **Chapter 5**). Finfish species composition within the bay was further studied through shore-based artisanal catch assessments, and we identified which fish species contribute to the bycatch in trawler catches in an attempt to evaluate resource use overlap between the artisanal fishery and bottom trawling (Munga et al., **Chapter 3**). Since the shrimp fishery management plan is based on a precautionary principle, the artisanal fishers' perceptions of bottom trawling activity and their livelihood alternatives were also studied to evaluate if this regulation is on the right track in addressing the sustainable resource use in the bay (Munga et al., **Chapter 6**).

1.13. Objectives and outline of the thesis

The overall objective of this study was to assess the current status of the Malindi-Ungwana Bay fisheries, both the artisanal fisheries and the semi-industrial bottom trawling before and after the 2006 trawling ban, and the associated conflicts that prevailed before the ban. The specific objectives were:

i. to determine the trends of the Malindi-Ungwana Bay artisanal fisheries and the semi-industrial bottom trawl landings before and after the trawling ban;

ii. to characterise the artisanal fisheries in terms of catch-per-unit-effort (CPUE) and catch composition;

iii. to determine the spatio-temporal distribution patterns and composition of stocks (shrimps and bycatch of finfish species) before lifting of the trawling ban;

iv. to determine fishers' perceptions on shrimp trawling activity and to what extent fishing activity contributes to the livelihood of the artisanal fishers in the Malindi-Ungwana Bay.

The broader framework and key features of this thesis are explained and introduced in **Chapter 1**. In order to achieve the specific objectives, this study used three approaches: retrospective analyses of the existing fisheries data, experimental bottom trawl surveys, shore-based artisanal catch assessments, and the socio-economic approach (Fig.13). In the retrospective data analyses (**Chapter 2**) bottom trawl landings data (shrimps and finfish bycatch) before the ban (2001 – 2006), and artisanal landings data (finfish and shrimps) data before trawling ban (2001-2006), and two years after the bottom trawl ban (2006-2008) were analysed for temporal trends and investigated the impact of bottom trawling on species distribution and artisanal landings. Shore-based artisanal catch assessments were undertaken along the bay for three years (2009-2011) to determine catch composition of finfish at species level, and the catch-per-unit effort (CPUE) for the artisanal fishery during the trawl ban (**Chapter 3**). To obtain the stock status and composition of shrimps and finfish bycatch after six years of no trawling in the bay, two experimental bottom trawl surveys were conducted in 2011, during the dry Northeast Monsoon (NEM) season and during the wet Southeast Monsoon (SEM) season (**Chapters 4 and 5**). The trawl surveys involved onboard data collection for biomass and catch rates analyses, laboratory-based biological shrimp data collection (visual gonad maturity identification and carapace length measurement), and physico-chemical water quality measurements. Finally a socio-economic survey was conducted on the artisanal fishers as household heads for their perceptions of the bottom trawling after the ban, and their alternative livelihoods as indicators of management satisfaction and level of ecosytem service (**Chapter 6**). The general discussion (**Chapter 7**) describes how this study has contributed to information for the application of Ecosystem

Approach to Fisheries (EAF) in the bay's fisheries resources, and provide conclusions based on the results of this study. Appropriate recommendations to ensure continued application of the EAF for sustainable management are also provided.

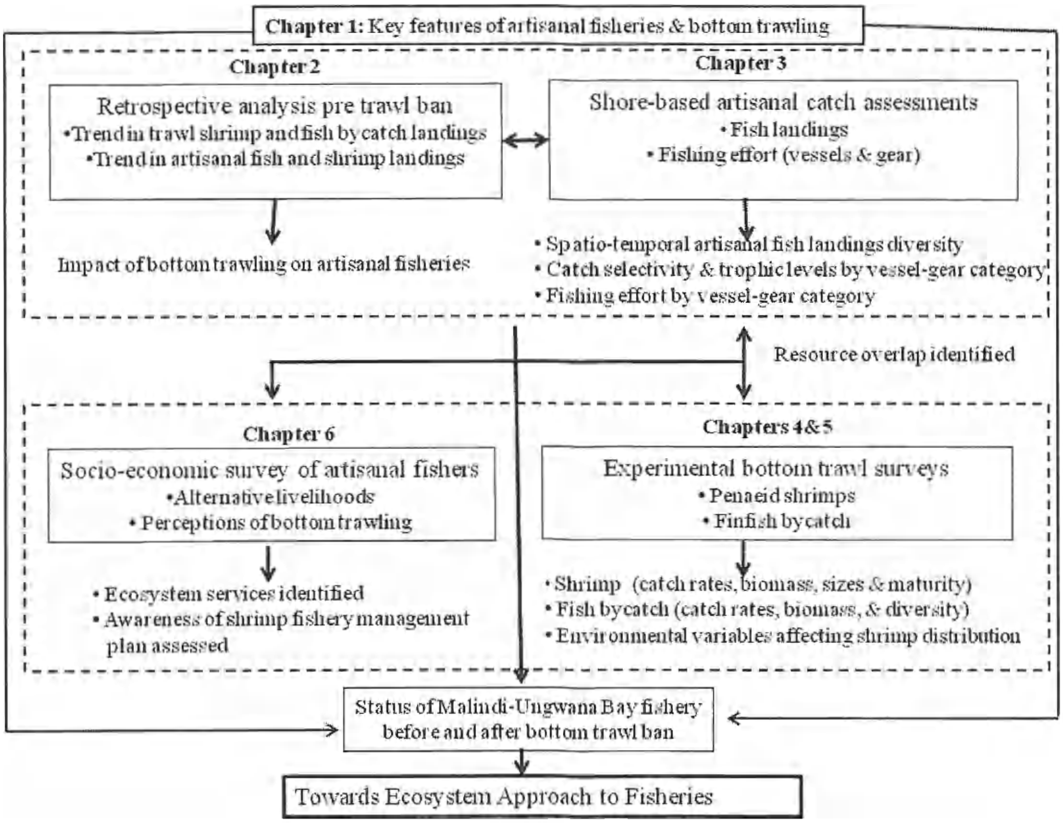

Figure 13. The study approach integrating ecological and socio-economic aspects towards contributing to EAF in the Malindi-Ungwana Bay fishery, Kenya.

Chapter 2

2. Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban

Cosmas N. Munga[1,6*], Stephen Ndegwa[2], Bernerd Fulanda[1,3], Julius Manyala[4], Edward Kimani[1], Jun Ohtomi[5] and Ann Vanreusel[6]

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

[2]Fisheries Department, P.O. Box 90423, Mombasa, Kenya.

[3]The United Graduate School of Agricultura Sciences, Kagoshima University, Korimoto 1-21-24, Kagoshima 890-0065, Japan.

[4]Department of Fisheries and Aquatic Sciences, University of Eldoret, P.O. Box 1125-30100, Eldoret, Kenya.

[5]Faculty of Fisheries, Kagoshima University, Shimoarata 4-50-20, Kagoshima 890-0056, Japan.

[6]Marine Biology Research Group, Gent University, Krijgslaan 281, S8, 9000 Gent, Belgium.

Modified from,

Munga, C., Ndegwa, S., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J. and Vanreusel, A. 2012. Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fisheries Science* 78: 209-219.

2.1 Abstract

The Malindi-Ungwana Bay, Kenya is one of the most important bottom trawl fisheries of the Western Indian Ocean region covering the trawling grounds off the Sabaki/Malindi in the south and Tana/Formosa in the north of the bay. The bay, after supporting both the artisanal fishery and bottom trawl fishery for several decades was faced with resource use conflicts. This culminated in a trawl ban in September 2006. This study analysed catches and fishery dynamics before and after the September 2006 trawl ban. Results show that artisanal landings declined before the ban, but rapidly recovered within 2 years after the ban was implemented. However, the artisanal shrimp landings remained low before and after the trawl ban. The trawl shrimp landings gradually declined before the ban from 550 t in 2001 to 250 t in 2006, and the shrimp to fish bycatch ratio was 1:1.5. Before the ban, distinct artisanal catch composition was evident between Formosa/Tana and Malindi/Sabaki areas. This difference was attributed to more abundant Claridae, Cichlidae and Protopteridae in Formosa, and more abundant mixed pelagics, mixed demersals, Carangidae, Siganidae, Carcharhinidae and Lethrinidae in Malindi. Future studies should therefore investigate the factors driving the spatio-temporal distribution, composition and abundance of both the artisanal and bottom trawl targeted species before the trawl ban can be lifted.

Key words: Malindi-Ungwana Bay Kenya; Bottom trawl; Artisanal fishery; Catch-per-unit-effort; SIMPER analysis.

2.2. Introduction

The Malindi-Ungwana Bay complex, Kenya, comprises the larger Ungwana Bay extending from Ras Shaka in the north of Kipini to Ras Ngomeni in the south, and the smaller Malindi Bay, which straddles the mouth of the Sabaki/Athi River (Fig. 1). The Malindi-Ungwana Bay waters provide fishing grounds for the bottom trawling fishery and the artisanal fishery in the offshore and inshore areas respectively. Two main rivers, the Sabaki and the Tana, drain into the bay. The bottom trawl fishery before the ban in September 2006, was by law restricted to the 5 nm offshore waters, while the 0–5 nm was for the artisanal fishery use (Government of Kenya, 1991). This fishery partitioning was to avoid conflict between the two fishery types in terms of resource use, but this was not so since trawlers contravened this regulation and trawled waters less than the designated 5 nm offshore.

The bottom trawl fishery in the bay dates back to the early 1970s being Kenya's only bottom trawl fishery (Nzioka, 1979; Saetersdal et al., 1993). The fishery targeted the five main penaeid species: *Fenneropenaeus indicus* H. Milne Edwards, *Penaeus monodon* Fabricius, *Metapenaeus monoceros* Fabricius, *Penaeus semisulcatus* De Haan and *Penaeus japonicus* Bate. The trawlers ranged in size from 25-40 m long with engine capacity of 115-1500 HP (Fulanda, 2003). The fleet size in the bay before the ban ranged between 4 and 5 vessels. The trawlers employed double-rigged, stern or outrigger trawling method, with funnel-shaped otter trawls (Fulanda, et al., 2011). The nets measured 50-55 mm and < 40 mm diamond mesh sizes at the body and cod-end, respectively.

The artisanal fishery has been in existence for several hundreds of years and is closely associated with trade dhows dating back to the 16th Century Arab invasion of the East African Coast (Datoo, 1974; Fulanda, et al., 2009). The vessels used in the artisanal fishery are mainly traditional canoes including *mtumbwi, hori, ngalawa* and *dau*, which account for more than 40%. The *Mtumbwi* are dug-out canoes measuring about 4 m long with curved bottom. On the other hand, the *hori* and *ngalawa* are canoes types made of plankwood (Fulanda, et al., 2011). The *dau* is a flat bottom, plankwood. The *mashua* and *jahazi* are mainly used for out-of-reef fishing using sails as main mode of propulsion. The artisanal fishery uses traditional fishing gear including basket trap (*malema*), weirs (*uzio*), spear guns (*bunduki*), and wooden spears (*ngovya*) for octopus and crab fishing (Fulanda, et al., 2011). Modern gear in the fishery is limited to gillnets, drift nets, beach seines, handlines and longlines. Sardine nets (*kimia*) with <5 cm mesh sizes are used to target the small sized sardine species (Hoorweg et al., 2008; Fulanda, et al., 2011).

Worldwide, resource use conflicts between the artisanal fishery and bottom trawling date back to several centuries. As early as the late 14^{th} Century, Jones (1992) identified historical complaints on bottom trawling by artisanal fishermen over indiscriminate harvesting of undersized and non-target species in New Zealand. In the Malindi-Ungwana Bay, conflicts in resource use between the artisanal and bottom trawling was experienced when trawlers encroached fishing grounds of less than the designated 5 nm offshore in such of better shrimp catches. The impact of bottom trawling on target and non-catch species, and the damage to habitats and the associated benthic biota have been studied (Jones, 1992; Kaiser and Spencer, 1996; Kaiser, et al., 1997; Jennings and Kaiser, 1998; Hall et al., 2000; Eyo et al., 2005). To date, bottom trawling continues to attract increasing criticism for both the perceived damage to the environment and its associated conflicts with other sectors, mainly the artisanal fishery. Many governments have devised harvest strategies incorporating seasonal bans and restricted fishing grounds, while others have banned bottom trawling altogether. Such management strategies have helped the recovery of the affected fisheries. For example, while assessing the effects of a 1978 sustained ban on trawling in an Indonesian shrimp fishery, Chong et al. (1987) reported that the over-fished stocks showed recovery within a 7 year period. With this background, the Kenya government imposed a ban on trawling in the Malindi-Ungwana Bay in September 2006. By the time of trawling ban, the status of the stocks and biology of the species was still lacking. Before and after the ban, attempts to contribute to scientific information for the trawl fishery were done through scientific trawl surveys. This include the 2002 trawl survey by the Kenya Marine and Research Institute (KMFRI, 2002); the 2003 survey by the joint Fisheries Department and Moi University (Government of Kenya, 2003);

the 2009 survey by the Kenya Coastal Development Project (KCDP, 2009), and the South West Indian Ocean Fisheries Project (SWIOFP, 2011) surveys. These surveys were aimed at contributing to information for the protection, management and development of the marine and coastal ecosystems of Kenya as outlined in the UNEP Nairobi Convention, 2010.

This present study therefore, investigated the fisheries status in the Malindi-Ungwana Bay between 2001 and September 2006 when bottom trawling was banned. Since bottom trawling was conducted for several decades before this study, earlier trawling impacts could not be detected with this present study and therefore, trawling impacts were limited to this investigated period. The study compared existing data on shrimp landings and retained fish bycatch for the bottom trawl fishery during 2001-2006, and landings data for the artisanal fishery during the 2001-2006 pre-trawl ban period and the 2006-2008 no-trawl years. The results of the study provide a baseline for future scientific assessments of the impacts of bottom trawling in the Malindi-Ungwana Bay.

2.3. Materials and methods

2.3.1. Study area

The Malindi-Ungwana Bay extends around 200 km long of coastal stretch running from Malindi in the south to Ras Shaka in the north of Kipini (Fig. 1). The bay straddles latitudes 2° 30' S and 3° 30' S, and longitudes 40° 00' E and 41° 00 'E. The fishing grounds in the bay cover an estimated 35,300 km^2 and the inshore area is characterized by non-continous fringing reef limiting the effective trawlable grounds to about 20,000 km^2 (Mwatha, 2002; Fulanda, et al., 2011). Most of the trawling is conducted in waters shallower than 70 m (Iverse, 1984; Fulanda et al., 2009). The Tana and Athi/Sabaki rivers drain into the bay, adding terrigenous sediments (Abuodha, 2003; Kitheka, 2005).

Like the rest of the East African coast, the bay experiences a tropical humid climate with two distinct seasons: the dry Northeast Monsoon (NEM) season (October-March) and the wet Southeast Monsoon (SEM) season (April-September) (McClanahan, 1988). These seasons greatly influence the productivity of the marine and coastal fisheries as well as the fishing patterns along the coast (McClanahan et al., 2002; Fulanda et al., 2011).

Figure 1. Map of the East African coast showing the location of the study site: the entire Malindi-Ungwana Bay, Kenya and demarcation of the Tana/Formosa and Malindi/Sabaki fishing grounds of the commercial bottom trawlers.

2.3.2. Data collection

Bottom trawling catch data between 2001 and September 2006 before the ban were obtained from the Kenya Fisheries Department. These were aggregated data for monthly total landings by weight of shrimps (target catch) and fish (bycatch) and the number of trawlers (trawling effort). Other details were fished areas, depths and daily tow durations. During this period, trawl catch data were recorded with the presence of Fisheries Department observers onboard. At the same time, vessels were installed with Turtle Excluder Devices (TEDs) which significantly reduced fish bycatch (Mwatha, 2005), and Vessel Monitoring System (VMS) installed. The artisanal fishery data were also annually aggregated, and a set of 2001 to 2008 was obtained from the Fisheries Department. During this period field staff from the Fisheries Department collected fish landings data from designated fish landing sites. The precision of data reporting in these sites has been enhanced by the recently initiated Beach Management Units (BMUs), a legal framework as a means of practicing collaborative fisheries management between the government and the local fishing community to increase management compliance. Data collected included total catch by weight and taxa (mostly family level) and fishing areas. Other details such as gear and vessel types, number of fishers, and active fishing time were not recorded which made calculation of catch-per-unit-effort (CPUE) imposible for the artisanal fishery.

2.3.3. Data analysis

The trawl shrimp CPUE was expressed in kg/h. The ratio of target catch (shrimps) against bycatch (fish) was calculated based on total catch weight of shrimps divided by fish bycatch (Table 1). In the fishery, discarding low value fish is common. This present study excluded the discarded bycatch quantities since data for this proprtion of catch was not available. Shrimp CPUE was analysed spatially and bathymetric by zoning the Formosa/Tana and Malindi/Sabaki trawling grounds into "shallow" ($\leq$25 m) and "deep" (>25 m). Differences in shrimp CPUE between years, seasons, trawling grounds, and depths were tested using the Kruskal-Wallis non-parametric test since homoscedascity of the variances was not fulfilled. The non-parametric test was conducted using STATISTICA v7.

The artisanal fishery 2001-2008 catch data were analysed for spatial and temporal composition in taxa and abundance using the non-metric Multidimensional Scaling (MDS). One-way ANOSIM was used to test for differences in catch composition between fishing areas, and 1-way SIMPER analysis was used to identify the dominant taxa contributing to the dissimilarity between the fishing areas. Both the ANOSIM and SIMPER use the Bray-Curtis measure of similarity. The SIMPER analysis breaks down the contribution of each taxon to the observed similarity (or dissimilarity) between samples and allows identification of taxa that are most important in creating the observed pattern. This multivariate analysis was conducted using PRIMER v6 software.

2.4. Results

2.4.1. Trends in landings and trawling effort

In the artisanal fishery, annual landings of both fish and shrimps generally oscillated, with no discernible trends during the study period. In this fishery, the annual landing of shrimps was less than 100 t throughout the investigated period 2001-2008 (Fig. 2). The annual fish landings recorded a peak of 1591 t before dropping to a lowest of 1106 t in 2006. After the trawl ban, artisanal fish catches showed a recovery increasing again to a peak of 1595 t in 2008. Between 2001 and 2006 at the time of the trawling ban, the number of operating trawlers (effort) in the bay ranged between 4 and 5 (Table 1).

Unlike the artisanal fishery, the bottom trawl fishery showed a clear downward trend, and shrimp catches declined by more than 50% during 2001-2006: from 554 t in 2001 to 257 t in 2006. During the same period, the retained fish bycatch was 432 t in 2001, increasing to 602 t in 2004, but declined to 316 t in 2006 before the trawl ban. The combined fish and shrimp landings during 2001-2006 averaged at 573-986 t, which is far lower than the artisanal fishery landings. The mean ratio of the target shrimp catch to the retained bycatch was 1:1.5.

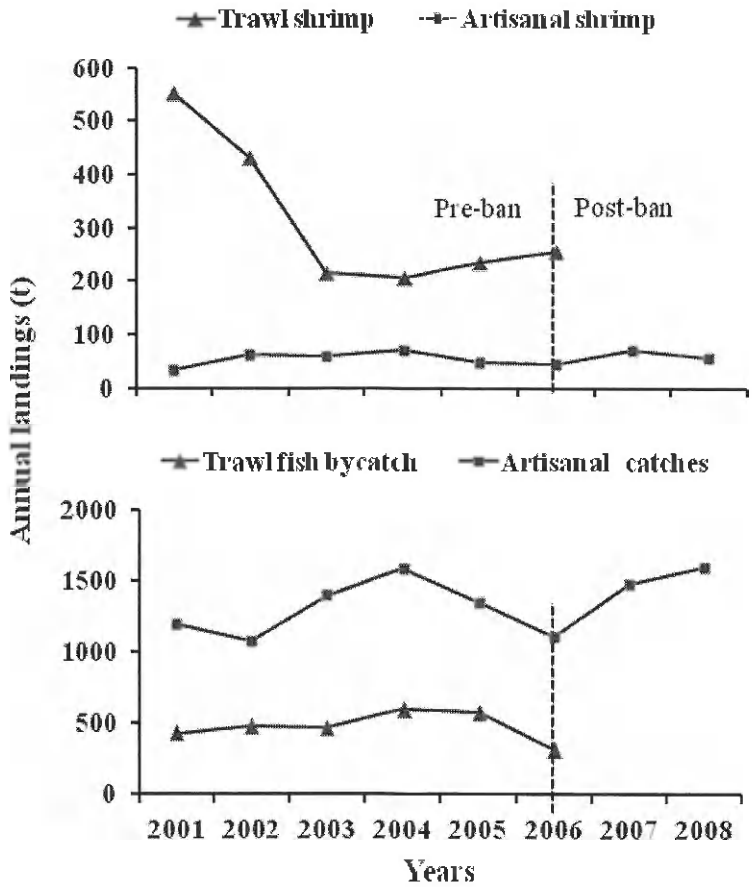

Figure 2. Annual landings of shrimp and fish in the artisanal and bottom trawl fisheries of the Malindi-Ungwana Bay, Kenya with vertical dotted line signifying time of trawl ban.

Table 1. Annual distribution of trawling effort before the ban on trawling towards in September 2006.

Vessel	Year	Months	Days	Hrs	Shrimp kg	Bycatch kg	Shrimp:bycatch
Amboseli	2001	12	324	3888	161487	123095	1:0.8
Manyara	2001	12	324	3888	152906	161190	1:1.1
Serengeti	2001	12	324	3888	152887	126082	1:0.8
VentureII	2001	4	108	1296	86378	21596	1:0.3
Amboseli	2002	12	324	3888	95179	117693	1:1.2
Manyara	2002	12	324	3888	122971	215220	1:1.7
Serengeti	2002	12	324	3888	138287	122102	1:0.9
VentureII	2002	4	108	1296	73148	23286	1:0.3
MVRoberto	2002	1	27	324	1424	3720	1:2.6
Amboseli	2003	9	243	2916	48458	124970	1:2.6
Manyara	2003	10	270	3240	58171	179290	1:3.1
Serengeti	2003	9	243	2916	54673	137160	1:2.5
VentureII	2003	8	216	2592	55546	27178	1:0.5
Amboseli	2004	6	162	1944	33612	105362	1:3.1
Manyara	2004	7	189	2268	38365	122038	1:3.2
Serengeti	2004	7	189	2268	43728	157454	1:3.6
VentureII	2004	8	216	2592	70198	196547	1:2.8
MVRoberto	2004	5	135	1620	20008	20932	1:1.0
Amboseli	2005	10	270	3240	60080	181287	1:3.0
Manyara	2005	10	270	3240	75575	188122	1:2.5
Serengeti	2005	10	270	3240	70045	200374	1:2.9
MVRoberto	2005	8	216	2592	20936	5162	1:0.2
MV Vega	2005	4	108	1296	9710	2827	1:0.3
Amboseli	2006	8	216	2592	77916	115664	1:1.5
Manyara	2006	8	216	2592	66620	108248	1:1.6
Serengeti	2006	9	243	2916	70644	86076	1:1.2
MVRoberto	2006	5	135	1620	42168	5577	1:0.1
Overall		222	5994	71928	1901120	2878252	1:1.5

Before the trawling ban in September 2006, shrimp CPUE ranged between a highest of 57.7 ± 4.4 kg/h in 2001 and a lowest of 23.5 ± 2.2 kg/h in 2005 before the ban in 2006 with a record of 35.7 ± 2.1 kg/h. Results of Kruskal-Wallis non-parametric test indicated significant difference in shrimp CPUE between the years ($p < 0.001$). Seasonal shrimp CPUE ranged between a highest of 64.3 ± 7.6 kg/h in the dry NEM season of 2001 and a lowest of 14.5 ± 7.8 kg/h the same season in 2004. During the wet SEM season, CPUE ranged between a highest of 51.7 ± 4.5 kg/h in 2001 and a lowest of 23.4 ± 2.1 kg/h the same season in 2003. Results of Kruskal-Wallis test however, indicated no significant difference in shrimp CPUE between the seasons ($p = 0.073$, Fig. 3).

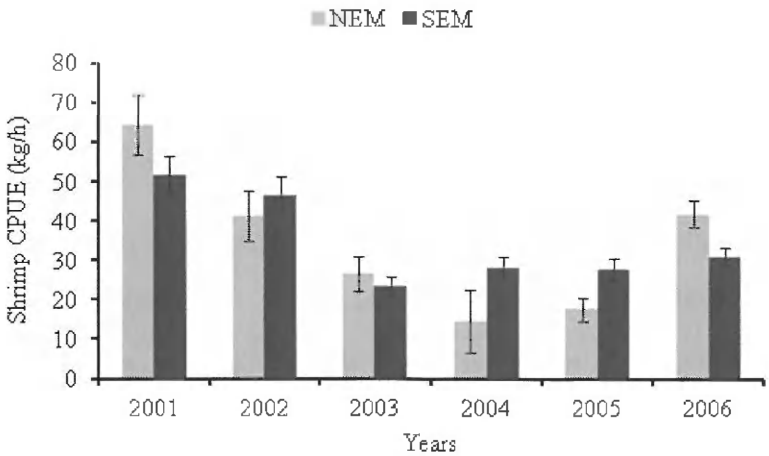

Figure 3. Mean seasonal trends in shrimp CPUE (kg/h ± SE) of bottom trawl fishery in Malindi-Ungwana Bay, Kenya from 2001 to 2006 in Northeast Monsoon (NEM) season and Southeast Monsoon (SEM) season.

2.4.2. Spatial and bathymetric distribution of shrimp CPUE in the bay

The overall mean CPUE was higher in Formosa (31.1 ± 0.4 kg/h) than in Malindi area (23.3 ± 0.6 kg/h). The Formosa "shallow" and "deep" recorded 31.2 ± 0.4 and 23.8 ± 2.5 kg/h compared to 22.2 ± 0.9 and 23.7 ± 0.7 kg/h in Malindi "shallow" and "deep", respectively (Fig. 4). Results of Kruskal-Wallis non-parametric test indicated significant difference in shrimp CPUE between the trawling areas and between the depth zones ($p < 0.001$ in both cases).

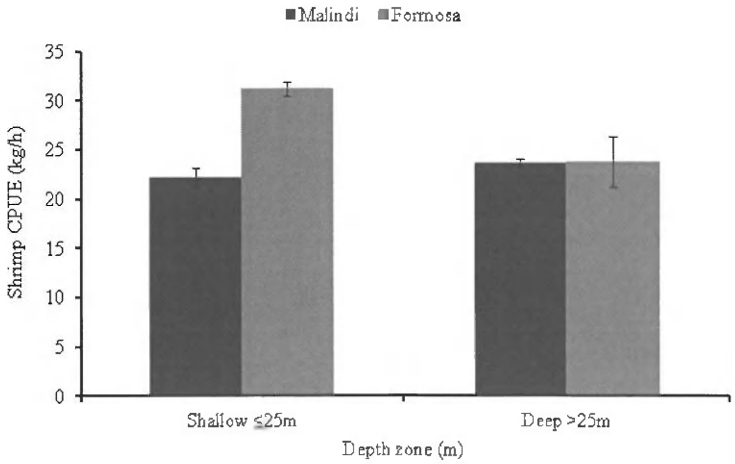

Figure 4. Mean shrimp CPUE ± SE by spatial and bathymetry in the Malindi-Ungwana Bay bottom trawl fishery, Kenya.

2.4.3. Variations in catch composition of the artisanal fishery

In 2001-2008, a total of 29 families and two ecological groups: "mixed pelagic" and "mixed demersal" comprising small-sized pelagic and demersal species of low commercial/food value, respectively were identified and used for ordination analysis of the artisanal fishery. Results of non-metric MDS indicated a distinct composition in the artisanal catches between the fishing areas of Formosa and Malindi (Fig. 5).

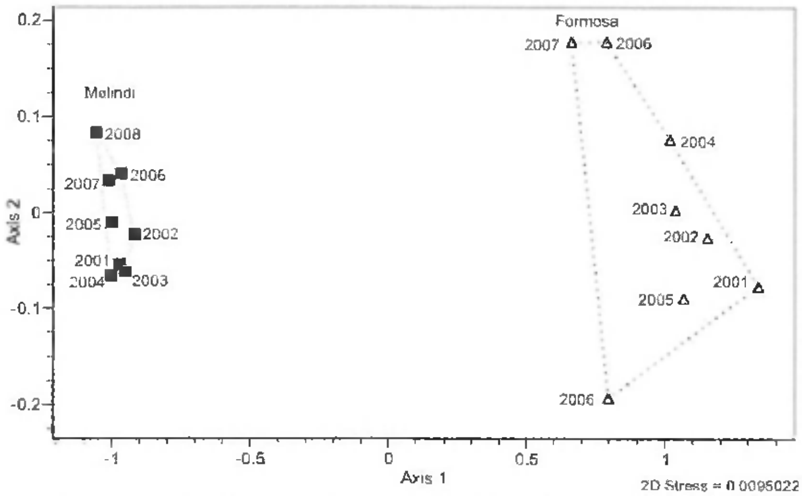

Figure 5. Non-metric MDS showing distinct catch composition of the artisanal catches between Formosa and Malindi fishing areas.

Results of 1-Way ANOSIM indicated a significant difference in artisanal catch composition between Formosa and Malindi areas ($R = 1.000$; $p = 0.001$). This difference in catch composition was attributed to more abundant brackish water and freshwater fish families of Claridae, Cichlidae and Protopteridae in Formosa, and more abundant mixed demersals, mixed pelagics, Carangidae, Siganidae, Carcharhinidae and Lethrinidae in Malindi (Table 2). The average similarity in catch composition for Formosa and Malindi was 80.8% and 80.5% respectively.

Table 2. One-way SIMPER Analysis: Artisanal catch taxa contributing to dissimilarity in terms of abundance (%) between Formosa and Malindi fishing areas of the Malindi-Ungwana Bay, Kenya. The average dissimilarity was 79.4%.

	Formosa area	Malindi area		
Fish taxa	Average abundance	Average abundance	Average diss	% contrib.
Claridae	37.83	0.00	18.92	23.83
Cichlidae	21.82	0.00	10.91	13.74
Protopteridae	14.87	0.00	7.43	9.37
Mixed pelagics	0.22	13.04	6.41	8.08
Mixed demersals	3.48	15.90	6.21	7.82
Carangidae	0.62	10.07	4.73	5.96
Siganidae	0.60	5.59	2.50	3.15
Lethrinidae	0.46	5.38	2.46	3.10
Carcharhinidae	3.14	6.64	1.99	2.50
Istiophoridae	0.32	3.93	1.80	2.27
Mugilidae	0.81	3.90	1.54	1.94
Scombridae	1.59	3.94	1.54	1.94
Acanthuridae	0.08	2.94	1.43	1.80
Lutjanidae	1.26	3.95	1.41	1.78
Palinuridae	3.60	1.79	1.15	1.45
Chanidae	0.17	2.11	0.98	1.24
Clupeidae	0.00	1.84	0.92	1.16
Serranidae	0.42	2.14	0.86	1.08
Sphyraenidae	0.32	2.04	0.86	1.08
Scaridae	0.36	2.02	0.83	1.04
Penaeidae	4.35	3.87	0.79	0.99
Octopodiformes	0.81	2.07	0.76	0.95
Portunidae	0.58	1.53	0.62	0.78
Ariidae	2.13	1.68	0.59	0.75
Plectorhinchidae	0.00	0.89	0.45	0.56
Decapodiformes	0.00	0.78	0.39	0.49
Coryphaenidae	0.08	0.73	0.34	0.42
Haemulidae	0.06	0.55	0.24	0.31
Ostreidae	0.00	0.37	0.19	0.23
Mullidae	0.03	0.23	0.11	0.14
Holothuroidae	0.00	0.04	0.02	0.03

2.5. Discussion

2.5.1. Trends in landings

Results of this study show that the combined fish and shrimp landings were higher in the artisanal fishery than in the bottom trawl fishery. However, it should be noted that the bottom trawl fishery was also characterised by proportions of discards that were not recorded, and at the same time the mandatory use of Turtle Excluder Devices (TEDs) and the presence of onboard observers significantly reduced the bycatches (Mwatha, 2005). Between 2001-2006, wide fluctuations in landings were observed especially in the artisanal fish catches but not in the artisanal shrimp catches. On the other hand, bottom trawl fishery recorded a downward trend throughout this period before its ban in September 2006. The fluctuations in artisanal landings may be attributed to variations in trawling activities related to the number of operational vessels during this period and fluctuations in fishing effort within the artisanal fishery. During this period under investiagtion, bottom trawl catches were also affected by new legislation of a closed season between November and end of March each year (Mwatha, 2002). This allowed recovery and breeding of trawled species in the bay (Nzioka, 1979; Mwatha, 2002).

The impacts of the extreme weather conditions associated with the 1997-1998 *El-Niño* may also partly explain the fluctuations due to long term effects of these conditions especially on the ecosystem. The *El-Niño* phenomenon may lead to tropicalization of the ecosystem, distruption of the normal food web, and induced changes in species composition and migrations of a large number of fish and invertebrate species populations, as noted in the South American Pacific Coast fishery after the 1982–1983 *El-Niño* (Arntz and Tarazona, 1990). Schwing et al., (2003) noted that the factors of concern are those affecting the general biological productivity and availability of food, aggregation for schooling and reproduction, larval dispersal, barriers to migration, physiological effects of extreme conditions, and changes in species composition and interactions. Although there exists no data to show the impact of *El-Niño* for Malindi-Ungwana Bay catches, recovery of fish species was reported in Kenyan Marine Protected Areas (MPAs) at least more than a year after the event (McClanahan, 2002). The decrease in artisanal catches between 2001 and 2002 in Malindi-Ungwana Bay, at least more than three years after *El-Niño* event, again coincided with the the overall decrease of artisanal catches reported in the south coast of Kenya three years after the event attributable to a 17% increase in the fishing effort (McClanahan et al., 2002). The steady increase in artisanal landings between 2002 and 2004 was attributed to the positive impact of the closed trawling season which reduced the number of trawling months in a year (Table 1). An increase in the trawling activities between 2004 and 2006, especially in 2005 before the trawl ban, and the continued encroachment into the artisanal Trawl Exclusion Zone (TEZ) grounds may also explain the decline in the artsanal landings during this period.

2.5.2. Composition of trawl and artisanal catches

Historically, bottom trawl catches in the Malindi-Ungwana Bay have been characterized by excessive discarding of especially finfish bycatches at sea. Since these discards were on the other hand targeted by the artisanal fishery, conflict between the two fishery types was inevitable, coupled with reported artisanal fishing gear distruction by the trawlers. In this study the overall ratio of shrimp to retained fish bycatch was 1:1.5, much lower compared to a ratio of 1:7 reported earlier in the same area (Fulanda et al., 2011). This disparity in shrimp to finfish bycatch ratios is attributed to the fact that before the trawling ban, catches of both the target and bycatch species had indicated highly fluctuating and to some extent declining (Fig. 2). In addition, the period between 2001 and 2006 was marked with increased trawling surveillance by the government through an observer program, mandatory use of Turtle Excluder Devices (TEDs) and prohibition of night trawling, which resulted to reduced trawl bycatches. Such surveillance was not implemented before this period under investigation, and this may explain the lower shrimp to bycatch ratio reported in this present study. The higher shrimp to bycatch ratio reported in the earlier study also included both the retained and discarded bycatche proportion, unlike the present study which considered only the retained bycatch. This ratio of shrimps to fish bycatch was based on what was produced from the trawlers and may not have been representative of the shrimps and fish populations in the bay.

In a separate study in the same area, the trawl total bycatch (retained and discarded) was estimated at 8 t/day, an average of 340 kg/trawler/h (Mwatha, 2002). In the same study, it was noted that over 25% of the discarded bycatch consisted of juveniles of commercial fish species including *Otolithes ruber*, *Johnius sp* (Sciaenidae) and *Pomadysis sp.* (Haemulidae), which are target species for the artisanal fishery. From the results of artisanal catch composition (Table 1), it is evident that the artisanal fishery targets what is available in the fishing grounds. Since data on trawl bycatches was only available in aggregated form, it is not possible to pin point exactly which artisanal catch taxa were affected by trawling activity during this period of investigation before the trawl ban. However, a clear indication is that, total catches by weight highly fluctuated with evident signs of declining at some point.

This study showed bottom trawl landings did not differ significantly between the seasons. This contrasts with earlier observations for the artisanal fishery where landings are likely to be significantly higher due to increased fishing frequency and access to a majority of the fishing grounds (Hoorweg et al., 2008) during the dry Northeast Monsoon (NEM) season. However, juvenile penaeid shrimps abundances, catchability and size have been reported to be affected by both season and depth. Bishop and Khan (1991) found that some species of the juvenile penaeid shrimps, especially *Metapenaeus affinis* (H. Milne-Edwards, 1837) were more catchable at shallower depths and bigger in size at deeper depths. The bottom trawl fishery in the Malindi-Ungwana Bay is predominantly shallow (Fulanda et al., 2011). There were however, significant differences in the spatial and bathymetric distribution of the shrimp CPUE between Malindi/Sabaki and Formosa/Tana trawled areas. The overall mean CPUE of shrimps for Formosa (31 kg/h) and Malindi (23 kg/h) reported in this review are much lower than that of 47 kg/h reported in a previous study in the same area (Mwatha, 2002). This present study has identified that Formosa area is important in artisanal fishery partly by the contribution of fresh and brackish water species. This is linked to the freshwater input from Tana River and its associated delta wetlands. However, Malindi area was equally important due to its significant contribution of marine fish catches mainly mixed pelagics, mixed demersals, the families Carangidae, Siganidae, Carcharhinidae and Lethrinidae.

2.5.3. Reasons for the trawl ban

Apart from the above discussed problems associated with bottom trawling, the ban on trawling in the bay allowed the Kenya Government to re-design strategic long-term sustainable resource use pattern for the bay. This involved a review of the existing fishery legislations by then, and also initiated through a stakeholder approach the formulation of a management plan for resource use of the bay. As a result, after four years, the shrimp fishery management plan was constituted and was ready for implementation by July 2011, about 6 years after the trawl ban. The management measures in the plan include: a minimum offshore trawling distance of 3 nm, observation of the closed season, mandatory use of TEDs, prohibition of night trawling, restriction of trawling effort amongst others.

In conclusion, these data for this current study were collected from the period during which regulation measures for the bottom trawl fishery had been initiated in the bay. The fluctuating artisanal landings may not only have been attributed to the variation in trawling effort but also in addition to changing artisanal effort and adverse weather conditions. Before lifting of the ban on trawling, there is need for further research on the status stocks and the environment. Also a detailed research on bottom trawl bycatches is required. Both the artisanal fishery and bottom trawl fishery seem to be dynamic and therefore continuous monitoring is recommended.

Acknowledgements

This publication was made possible by the Flemish VLIR ICP scholarship funding in collaboration with the Marine Biology Research Group of Gent University, Belgium. The authors express their gratitude to the Director of Kenya Marine & Fisheries Research Institute for the logistical support, and the Fisheries Department for providing the archived fisheries data.

Photo credit: C.N. Munga, 2010 at Ngomeni fish landing site in Malindi-Ungwana Bay, Kenya.

Chapter 3

3. Vessel-gear-based characterisation of artisanal fisheries in the Malindi-Ungwana Bay, Kenya and its use for fisheries management

Cosmas N. Munga[1,2*], Johnstone O. Omukoto[1], Edward N. Kimani[1] and Ann Vanreusel[2]

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

[2]Gent University, Marine Biology Research Group, Krijgslaan 281-S8, 9000, Gent, Belgium.

Submitted to Ocean & Coastal Management, OCMA-D-13-00230.

3.1. Abstract

In Kenya, like other tropical countries, coastal artisanal fisheries is multispecies, multigear and multifleet in nature with many management challenges. The Malindi-Ungwana Bay in particular, supports both the artisanal fishery and the semi-industrial bottom trawl shrimp fishery presenting a management challenge. While recent stock assessment surveys have identified catch composition of the semi-industrial bottom trawl fishery in the bay, artisanal catches remain barely described. This study describes, the artisanal finfish catch composition (total number of species caught, sizes and trophic levels), and catch-per-unit-effort (CPUE) for each of the most popular vessel-gear categories used in the bay. We make a case that the use of specific vessel-gear categories can be dynamically managed to encourage the recovery of selected fish groups and thus support fisheries management. A total of 4,269 finfish belonging to 178 species and 66 families were sampled by the 5 most popular vessel-gear categories between 2009 and 2011. The total number of species caught was highest for canoe-gillnet and *mashua*-gillnet, and lowest for foot-handline and *mashua*-handline. Significant differences in catch composition existed between the different vessel-gear categories. The CPUE was not significantly different between vessel-gear, although this was on the average highest for canoe-gillnet and *mashua*-gillnet, and lowest for the foot-handline. The highest trophic level of 4.0 was recorded for *mashua*-gillnet and the lowest 3.4 and 3.2 for canoe-gillnet and foot-seine net respectively. The use of specific combinations of vessel-gear categories, give an alternative approach in management recommendation of the coastal artisanal fisheries in the tropics, from the traditional gear-based management initiative. This study, singled out the *mashua*-gillnet, canoe-gillnet and foot-seine net as suitable units for monitoring the artisanal fisheries in Malindi-Ungwana Bay by virtue of landing highest mean trophic level and largest sized individuals for the *mashua*-gillnet, highest number of species caught for the canoe-gillnet, and smallest sized individuals for the foot-seine net.

Key words: Artisanal fishery; Catch composition; Catch-per-unit-effort; Trophic level; Vessel-gear category; Malindi-Ungwana Bay; Kenya.

3.2. Introduction

Sustainable management of coastal artisanal or small-scale fisheries in the tropics is challenging due to the multigear, multispecies and multifleet nature and the lack of adequate resources to conduct scientific studies, monitoring and enforcement (McClanahan and Mangi, 2004). Catch-per-unit-effort (CPUE) and species composition of catches are used to guide management but are difficult to establish due to the lack of long term and accurate artisanal fisheries data (McClanahan and Mangi, 2004; Marquez-Farias, 2005; Cinner et al., 2009; Kronen et al., 2012). Nevertheless, there is a growing awareness that reliable knowledge on trends in catch composition and selectivity of commonly used gear is important for management recommendations (Gobert, 1994; McClanahan and Mangi, 2004). Therefore, artisanal fisheries is receiving increasing attention from scientists and environmental managers for various ecological and socio-economic reasons, including user conflicts, habitat destruction and stock depletions. Furthermore, the current climate change phenomenon is an additional challenge to the management of especially reef-based fisheries as reef habitats are getting destroyed under unprecedented pressure (Cinner et al., 2009).

So far, only a few studies in the tropics including Kenya, Madagascar and New Papua Guinea examined species selectivity by gear and recommended for gear-based artisanal fisheries management (McClanahan and Mangi, 2004; Mangi and Roberts, 2006; McClanahan and Cinner, 2008; Cinner et al., 2009; Davies et al., 2009). However, these studies did not address species selectivity by combined vessel-gear category whereas many studies only dealt with species and size selectivity based on gillnet mesh sizes (MacLennan, 1992, 1995; Chopin and Arimoto, 1995; Stergiou and Erzini, 2002; Marquez-Farias, 2005; Matic-Skoko et al., 2011). Furthermore artisanal fishing grounds in the tropics are remarkably heterogeneous, ecologically diverse and variably accessible depending on vessel/craft, gear and season, which makes it difficult to identify catch composition. In Kenya, such fishing habitats have been identified as lagoon and inshore areas, the reef itself, fishing grounds beyond the reef and offshore relatively deep waters (Hoorweg et al., 2008).

In the Malindi-Ungwana Bay, Kenya, artisanal fisheries is restricted to the inshore fishing grounds mostly less than 3 nautical miles (nm) due to inability of the traditional vessels to access offshore fishing grounds. These inshore fishing grounds, are also the main shallow water shrimp trawling grounds (Mwatha, 2005; Munga et al., 2012a; Munga et al., 2013) resulting in user conflict between the artisanal and semi industrial shrimp trawl fisheries. Since the promulgation of the shrimp fishery management plan in 2011, conflicts between the two fishery types are hoped to be resolved. The shrimp fishery management plan ensures sustainable semi-industrial trawling based on a precautionary principle since little information about the ecosystem is known. The management plan, does not provide any management recommendations for the artisanal fishery which uses diverse fishing methods including the illegal beach seines (McClanahan and Mangi, 2004; Mangi and Roberts, 2006; Davies et al., 2009). In addition, the management plan lacks an adequate scientific basis to guarantee implementation of an appropriate ecosytem approach to fisheries (EAF). Artisanal fleet in the bay consists of a variety of traditional wooden vessels including *mtumbwi, hori* and *dau* (here collectively referred to as canoes), *ngalawa* (outriggers pointed at both ends), *mashua* (bigger plankwood boats pointed at one end) to dinghies and surf boards (Fulanda et al., 2009; 2011). Fishing gear in use include traps (fixed and portable), spear guns, gill nets, seine nets, longlines, handlines, cast nets and recently ring nets (McClanahan and Mangi 2004; Fulanda et al., 2009; 2011). Approximately 3,500 artisanal fishers operate more than 600 traditional fishing vessels targeting both finfish and shellfish species in the bay (Fulanda et al., 2011), with estimated landings of between 1,014 – 1,653 t annually (Munga et al., 2012a). Most fishing activities take place between October and March during the Northeast Monsoon (NEM) season when the sea is warmer and calmer compared to the Southeast Monsoon (SEM) season (April to September) with cool and rough sea (McClanahan, 1988).

This study for the first time describes the Malindi-Ungwana Bay artisanal finfish landings composition between 2009 - 2011 (total number of species caught, sizes, and trophic levels), and catch-per-unit-effort (CPUE) based on the most popular artisanal vessel-gear categories used in the bay. The study tests the following hypotheses: i) different vessel-gear categories constitute different seasonal finfish landing compositions and therefore, ii) different catch selectivity, iii) different trophic levels; and iv) different seasonal CPUE.

3.3. Materials and methods

3.3.1. Data collection

Shore-based catch assessments were conducted in 2009 (10th- 18th June; 6th- 7th November; and 2nd-4th and 6th- 7th December), 2010 (4th- 6th March; 26th- 30th June; and 25th- 27th September), and 2011 (3rd- 14th March; 20th- 24th July; and 22nd- 26th September) in three major fishing areas: Malindi, Ngomeni and Kipini located along the 200 km long Malindi-Ungwana Bay (Fig. 1) totalling 49 shore visits and 85 samples covering both the NEM and SEM seasons. The bay is located between the latitudes 2° 30'S and 3° 30'S, and the longitudes 40° 00'E and 41° 00'E and extends from Malindi through Ras Ngomeni in the south to Ras Shaka in the north. At the Tana River estuary, the bay is shallow and extends between 8 and 32 nm. The mean depth at spring high tide is 12 m at 1.5 nm, and 18 m at 6.0 nm from the shore. The depth increases rapidly to 100 m after 7 nm from the shore. Near the Sabaki River estuary, the inshore area is narrow, stretching between 3 and 5 nm offshore, whereafter depth rapidly increases to 40 m (Kitheka et al., 2005).

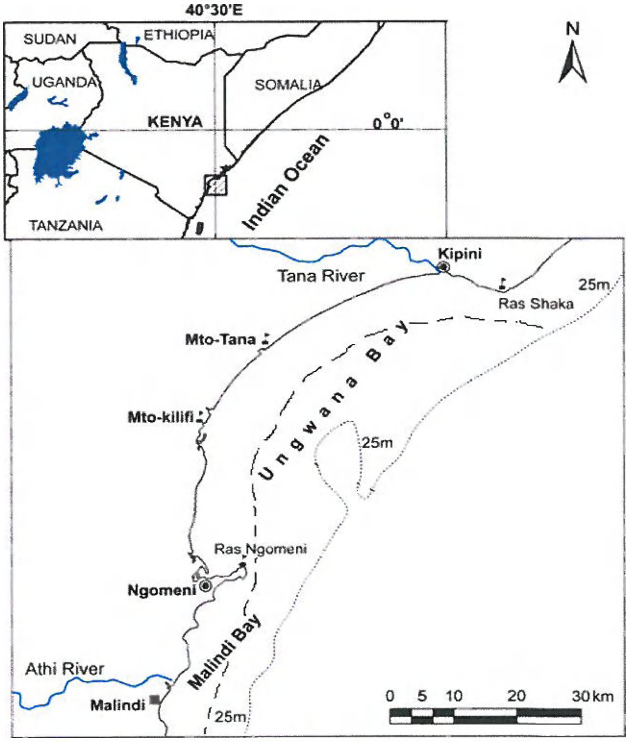

Table 1. Map of East African coast showing location of the study site: the Malindi-Ungwana Bay, Kenya and a demarcation of the 3 nm offshore artisanal fishing grounds (black dotted line, modified from Munga et al., 2012a).

At the landing sites, finfish landings were examined during the day from collaborative fishers returning from fishing. Sampling was randomly performed to all the artisanal fishers. Because fishers are always in a hurry to sale their catches sometimes they become uncollaborative when scientists want to sample their catches. This means you have to convince them by promising them to take the shortest time possible. Most times they agreed and sampling was quickly done, but a few cases they did not agree. Fish landing data either for the night time or from occasionally uncollaborative fishers is therefore excluded in this analysis. For large catches, total weight was measured using a weighing balance before a homogeneous mixture was made, and a random sub-sample taken for individual fish length measurement and total weight by species. For small catches, all fish were measured and weighed by species. Fish species were identified using van der Est, (1981), Smith and

Heemstra, (1986) and Lieske and Myers, (1994). Total length (TL) of individual fish was measured using a fixed marked ruler on a flat board. Gear type, craft/vessel type, number of fishers, duration (hrs) of fishing activity were also recorded (Table 1). A total of 9,501.7 kg of finfish was weighed during this study and a sub-sample of 2,236.7 kg (proportion of 23.5 %) was used for the enumeration of number of individuals per species, identification of species and TL measurements.

Table 1. Frequency of use (a) vessel/craft types, (b) gear types and (c) most popular vessel-gear combinations sampled off the Malindi-Ungwana Bay, Kenya during the study period.

a			b			c		
Vessel/craft	Count	% freq.	Gear type	Count	% freq.	Vessel-gear	Count	% freq.
Mashua	162	37.9	Gillnet	194	45.3	Mashua-gillnet	116	41
Foot	124	29	Handline	127	29.7	Foot-seine net	74	26
Canoe	63	14.8	Seine net	79	18.5	Canoe-gillnet	39	14
Surf board	46	10.8	Longline	19	4.4	Mashua-handline	33	12
Dinghy	25	5.9	Speargun/harpoon	4	0.9	Foot-handline	18	6
Outrigger	4	0.9	Basket trap	1	0.2	-	-	-
Motor boat	3	0.7	Cast net	1	0.2	-	-	-
-	-	-	Ring net	1	0.2	-	-	-

3.3.2. Data analyses

Catch-per-unit-effort (CPUE) by season was calculated for the most popular vessel-gear categories used in the bay: canoe-gillnet, foot-seine net, foot-handline, *mashua*-gillnet and *mashua*-handline. These vessel-gear categories were used by the highest proportion of fishermen in the bay. These fishing gear are legal by law and are not associated with any discarding of bycatch (Mangi and Roberts 2006). For each vessel-gear category, totals of catch landed in a day were divided by the number of fishers. The average catch (kg/fisher), was divided by the fishing time (h), and CPUE expressed in kg/fisher.h. Differences in CPUE and total number of species expected in each ten individuals sampled between vessel-gear catagories and seasons were determined using 2-way ANOVA. The same test was used for differences in fish sizes (mean TL) and mean trophic level. Differences in sizes of individual fish species between vessel-gear categories were tested by 1-way ANOVA, as number of individuals of most species were not always sufficiently high for both seasons. All the ANOVA tests were followed by a post hoc pair-wise comparison using the Tukey HSD test, and Levene's test was used for homoscedascity of the variances. Where necessary, data were appropriately transformed. All parametric univariate tests were performed using STATISTICA v7. The individual fish species trophic levels were obtained from FishBase (Froese and Pauly, 2011). Trophic level estimates for each species are based on diet composition data compiled in FishBase where the trophic level of each fraction of the diet of fish is used to calculate the mean trophic level for the species. Since plants, macroalgae and detritus are defined as trophic level 1, the following fish trophic levels were used: herbivores as trophic level 2, omnivores as trophic level 3, and carnivores as trophic level 4. The mean trophic level of the catch by vessel-gear category *k* was calculated as:

$$\overline{TL_k} = \sum_{i=1}^{m} Y_{ik} TL_i \Big/ \sum_{i=1}^{m} Y_{i,k}$$

where Y_{ik} is the landings/catch of species *i* in vessel-gear category *k*, TL_i is the trophic level of species *i* for *m* fish species which was also used to calculate the standard error (SE) of the mean trophic level (Pauly et al., 2001). This analysis however, does not take into consideration of ontogenetic diet shifts of the fish species. The mean trophic levels were also correlated with the mean total lengths by vessel-gear categories.

Differences in multivariate species composition between vessel-gear categories and seasons were visualised with non-metric Multidimensional Scaling (MDS) on the basis of Bray Curtis similarities between samples of standardised data. Two-way ANOSIM test was performed to determine the magnitude of seasonal differences in catch composition, and differences between the vessel-gear categories. Species contributing most to the separation of catches between vessel-gear categories and seasons were determined using a 2-way SIMPER analysis. This analysis indicated the average contribution of each species to the dissimilarity between groups of samples. All the multivariate analyses were performed using PRIMER v6 software (Clarke and Warwick, 2001).

3.4. Results

3.4.1. Seasonal catch-per-unit-effort by vessel-gear category

A total of 7 craft/vessel types, 8 gear types and 5 most popular vessel-gear combinations were recorded in this study (Table 1). The crafts (or propulsion mode) were in decreasing order of use the *mashua* (37.9%), by foot or no vessel (29.0%), and canoes (14.8%), whereas gillnets (45.3%), handlines (29.7%) and seine nets (18.5%) represented the most popular fishing gear. The *mashua*-gillnet (41%) was the most popular vessel-gear category followed by the foot-seine net (26%). The canoe-gillnet (14%), *mashua*-handline (12%) and foot-handline (6%) followed in that order (Table 1). Duration in terms of active fishing time spent at sea by vessel-gear category was longest for *mashua*-handline (on average 11.4 hours per day) and lowest for the foot-seine net and foot-handline (on average 3.2 and 3.7 hours per day respectively), while for the *mashua*-gillnet and canoe-gillnet, the active fishing time at sea was intermediate on average 6.5 and 5.2 hours per day respectively.

The highest CPUEs were recorded in canoe-gillnet and *mashua*-gillnet, and the lowest recorded in foot-handline and foot-seine net (Fig. 2). Results of 2-way ANOVA however, indicated no significant difference in CPUE between the vessel-gear categories, and between the seasons (Df = 4; Err Df = 222; F = 2.393; p = 0.052 and Df = 1; Err Df = 222; F = 0.716; p

= 0.399 respectively). The same test indicated no significant effect due to the interaction of vessel-gear category with season (Df = 4; Err Df = 222; F = 1.826; p = 0.125).

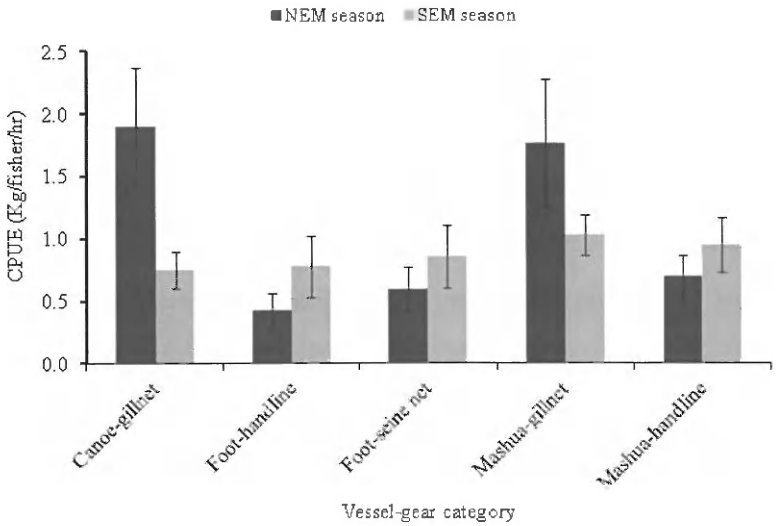

Figure 2. Mean CPUE (kg/fisher/h ± SE) by the different vessel-gear categories in the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons in the Malindi-Ungwana Bay, Kenya artisanal fishery.

3.4.2. Finfish species diversity, mean trophic levels and selectivity by vessel-gear category

A total of 4,269 finfish individuals belonging to 178 species in 66 families were landed by the identified most popular vessel-gear categories in the bay. Rarefaction curves for all the five vessel-gear categories for both seasons combined (Fig. 3), indicated that canoe-gillnet caught the highest number of fish species followed by the *mashua*-gillnet and foot seine net. The lowest number of species was caught by the foot-handline and *mashua*-handline. Excluding the foot-handline with the fewest samples, results of 2-way ANOVA indicated no significant difference in the exepected total number of species caught for every ten individuals sampled (Fig. 4) neither between the vessel-gear categories nor between the seasons (Df = 3; Err Df = 59; F = 1.127; p = 0.346 and Df = 1; Err Df = 59; F = 2.351; p = 0.131 respectively). The same test however, indicated a significant effect due to the interaction of vessel-gear category with season (Df = 3; Err Df = 59; F = 9.298; $p < 0.001$).

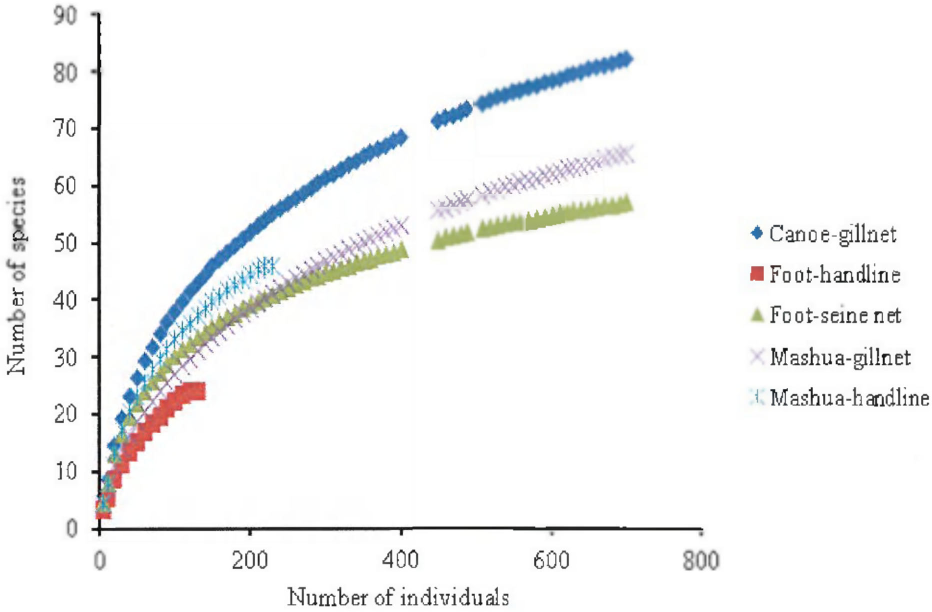

Figure 3. Rarefaction curves indicating the total number of fish species caught by vessel-gear category with all seasons combined in the Malindi-Ungwana Bay, Kenya.

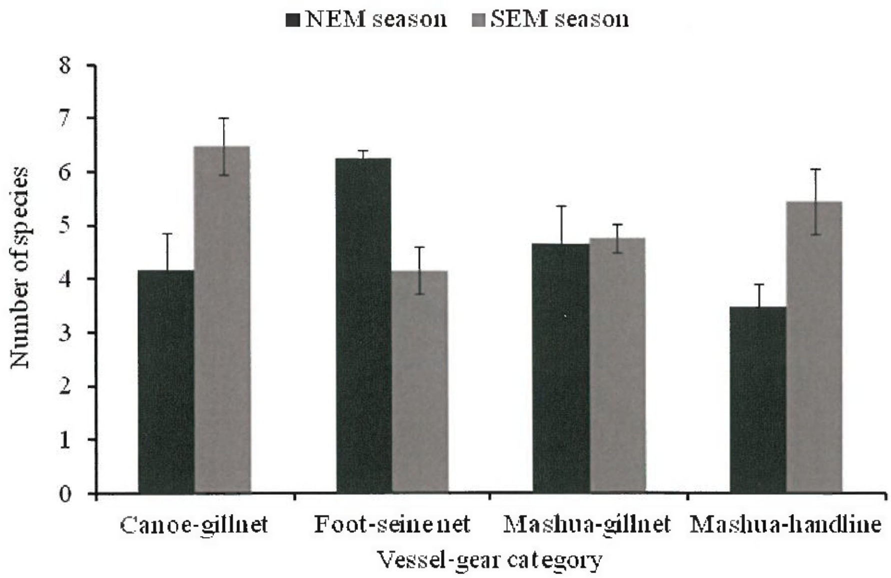

Figure 4. Mean expected number ± SE of species caught in every ten samples (ES(10)) by vessel-gear during the Northeast (NEM) and Southeast Monsoon (SEM) seasons in the Malindi-Ungwana Bay, Kenya. Data for foot-handline is not given due to lowest number of individuals sampled.

The largest individuals of fish were landed by *mashua*-gillnet measuring mean TL of 56.1 cm, and foot-seine net landed the smallest individuals measuring mean TL of 17.9 cm (Fig. 4). The *mashua*-handline landed a mean size of 49.7 cm, canoe-gillnet 23.1 cm, and foot-handline with a mean size of 20.7 cm. Results of 2-way ANOVA indicated no significant difference in mean TL of finfish landings between the seasons (Df = 1; Err Df = 4914; F = 1.600; p = 0.212), but a highly significant difference between the vessel-gear categories existed (Df = 4; Err Df = 4914; F = 1124.200; p < 0.001). The same test indicated a significant effect due to the season-vessel-gear category interaction (Df = 4; Err Df = 4914; F = 27.500; p < 0.001). Results of post hoc pair-wise comparison indicated that mean TL of finfish from canoe-gillnet, foot-seine net and foot-handline in both seasons, were significantly smaller compared to those of *mashua*-gillnet and *mashua*-handline in both seasons (p < 0.05). Pelagic finfish landings was higher in composition in *mashua*-gillnets than demersals at

57.3% and 42.7% respectively. In *mashua*-handline demersals made 78.7% in composition, much higher than pelagics at 21.3%. The canoe-gillnet had 62.4% composition of demersals and 37.6% pelagics. Demersal composition in foot-handline was 94.1% and only 5.9% was composed of pelagics. Demersal composition was also higher in foot-seine net at 54.1% than pelagics at 45.9%.

Different vessel-gear categories resulted in different composition in finfish landings (Fig. 5). Two-way ANOSIM combining vessel-gear category with season indicated significant difference in finfish landing compositions between the vessel-gear categories and to a lesser extent between the seasons ($R = 0.510$; $p = 0.001$ and $R = 0.194$; $p = 0.036$ respectively). The difference in finfish landings composition between the different vessel-gear categories are confirmed with the results of pair-wise comparison tests (Table 3: $p < 0.05$).

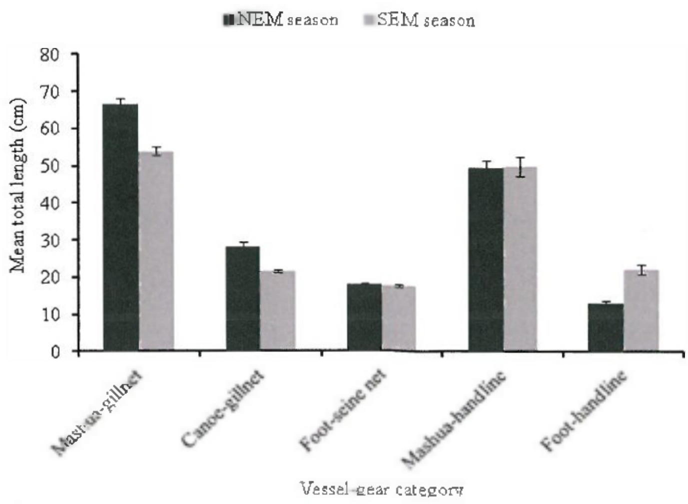

Figure 4. Mean total length (TL cm ± SE) of finfish landings by vessel-gear category in the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons in the Malindi-Ungwana Bay, Kenya.

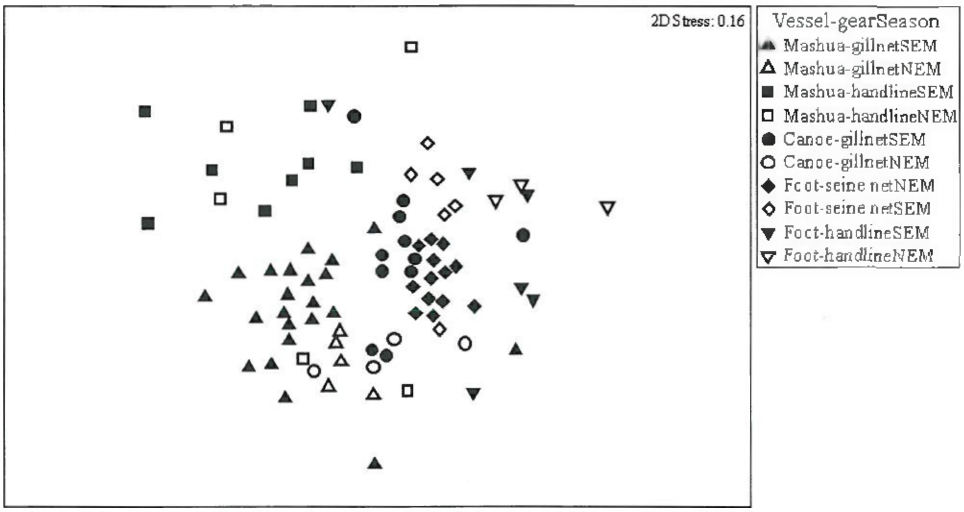

Figure 5. Non-metric MDS plot showing the similarities in relative composition (%) of artisanal finfish landings by vessel-gear categories during Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons sampled in the Malindi-Ungwana Bay, Kenya.

Table 3. Results of pair-wise comparison tests showing vessel-gear category comparisons in catch composition (p < 0.05, bold and italic) in the Malindi-Ungwana Bay, Kenya.

Vessel-gear category	R Statistic	p Value	Possible Permutations	Actual Permutations	Number >= Observed
Mashua-gillnet, Mashua-handline	0.481	***0.001***	Very large	999	0
Mashua-gillnet, Canoe-gillnet	0.393	***0.001***	Very large	999	0
Mashua-gillnet, Foot-seine net	0.625	***0.001***	Very large	999	0
Mashua-gillnet, Foot-handline	0.553	***0.001***	33251400	999	0
Mashua-handline, Canoe-gillnet	0.492	***0.001***	9523332	999	0
Mashua-handline, Foot-seine net	0.731	***0.001***	25729704	999	0
Mashua-handline, Foot-handline	0.281	***0.006***	168168	999	5
Canoe-gillnet, Foot-seine net	0.526	***0.001***	29454880	999	0
Canoe-gillnet, Foot-handline	0.39	***0.001***	433160	999	0
Foot-seine net, Foot-handline	0.784	***0.001***	258720	999	0

Results of 2-way SIMPER analysis indicated a total of 14 most abundant finfish species that caused the variation in species composition between the vessel-gear categories

(Fig. 6). The *mashua*-gillnet landed mostly *Lobotes surinamensis, Psettodes erumei, Galeichthys feliceps* and *Carcharhinus melanopterus*. *Lethrinus lentjan* and *Acanthurus xanthopterus* were mostly landed by the *mashua*-handline. The canoe-gillnet mostly landed *Galeichthys feliceps*, *Thryssa vitrirostris* and *Otolithes ruber*. *Pellona ditchela, Lutjanus fulviflamma, Siganus sutor, Leptoscarus vaigeinsis* and *Hilsa kelee* were mostly landed by the foot-seine net, whereas the foot-handline mostly landed *L. fulviflamma* and *Acanthopagrus berda*. Generally there was an average dissimilarity of 86.4 % of finfish landing composition between the NEM and SEM seasons, and the abundance of the 14 finfish species also varied between the seasons with the majority of these species being more abundant during the NEM season (Table 4).

Table 4. SIMPER results showing seasonal composition (%) during Northeast Monsoon (NEM) and Southeast Monsoon (SEM) of the most abundant finfish species that caused the variation in species composition between vessel-gear categories in the Malindi-Ungwana Bay, Kenya.

	SEM season	NEM season		
Species	Avg. abundance	Avg. abundance	Avg. dissimilarity	% contrib.
Galeichthys feliceps	2.59	9.46	8.63	9.98
Lobotes surinamensis	6.77	8.12	6.18	7.15
Psettodes erumei	9.53	0.05	4.34	5.02
Otolithes ruber	1.50	7.91	3.55	4.11
Thryssa vitrirostris	0.39	6.91	3.23	3.74
Lutjanus fulviflamma	5.90	7.88	3.22	3.73
Pellona ditchela	1.23	8.93	3.04	3.51
Siganus sutor	3.72	3.29	2.52	2.92
Hilsa kelee	2.35	0.32	2.50	2.90
Lethrinus lentjan	1.54	4.04	1.92	2.22
Carcharhinus melanopterus	3.75	0.49	1.86	2.16
Acanthurus xanthopterus	0.45	4.13	1.69	1.96
Leptoscarus vaigiensis	0.45	3.67	1.13	1.30
Acanthopagrus berda	2.45	0.00	0.82	0.95

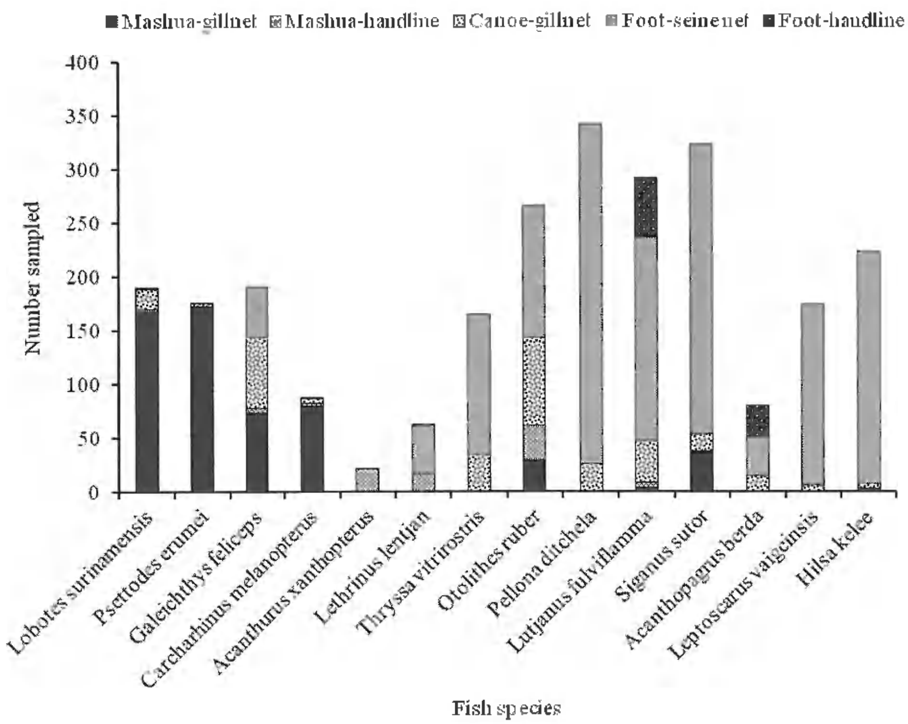

Figure 6. Selectivity by vessel-gear category for finfish species responsible for differences between vessel-gear categories identified by SIMPER in the Malindi-Ungwana Bay, Kenya.

Lutjanus fulviflamma was landed by the canoe-gillnet, foot-seine net and foot-handline at mean TL of 18.49 ± 0.67 cm, 15.20 ± 0.26 cm and 15.08 ± 0.56 cm respectively. There was significant difference in mean TL between the vessel-gear categories (Df = 2; Err Df = 281; F = 13.073; $p < 0.001$), and results of pair-wise comparison confirmed that significantly larger *L. fulviflamma* individuls were landed by the canoe-gillnet. Length frequencies of this species for these vessel-gear categories indicate size selectivity of canoe-gillnet for larger *L. fulviflamma* individuals of 14 cm and above (Fig. 7a). *Galeichthys feliceps* was landed by the *mashua*-gillnet, canoe-gillnet and foot-seine net at mean TL of 59.49 ± 1.79 cm, 33.36 ± 1.18 cm and 21.64 ± 0.83 cm respectively. The mean TL of *G. feliceps* individuals differed significantly between the vessel-gear categories (Df = 2; Err Df =

183; $F = 190$; $p = 0.000$), and results of post hoc pair-wise comparison confirmed this difference ($p < 0.05$). The length frequency (Fig. 7b) showed *mashua*-gillnet selected for the largest individuals of this species. The canoe-gillnet and foot-seine net on the other hand, both landed *Otolithes ruber* measuring mean TL of 25.72 ± 0.52 cm and 21.44 ± 0.47 cm respectively. The mean TL were significantly different between these vessel-gear categories ($Df = 1$; Err $Df = 203$; $F = 36.103$; $p = 0.000$). A distinct size selectivity was observed in canoe-gillnet for more larger *O. ruber* individuals (Fig. 7c).

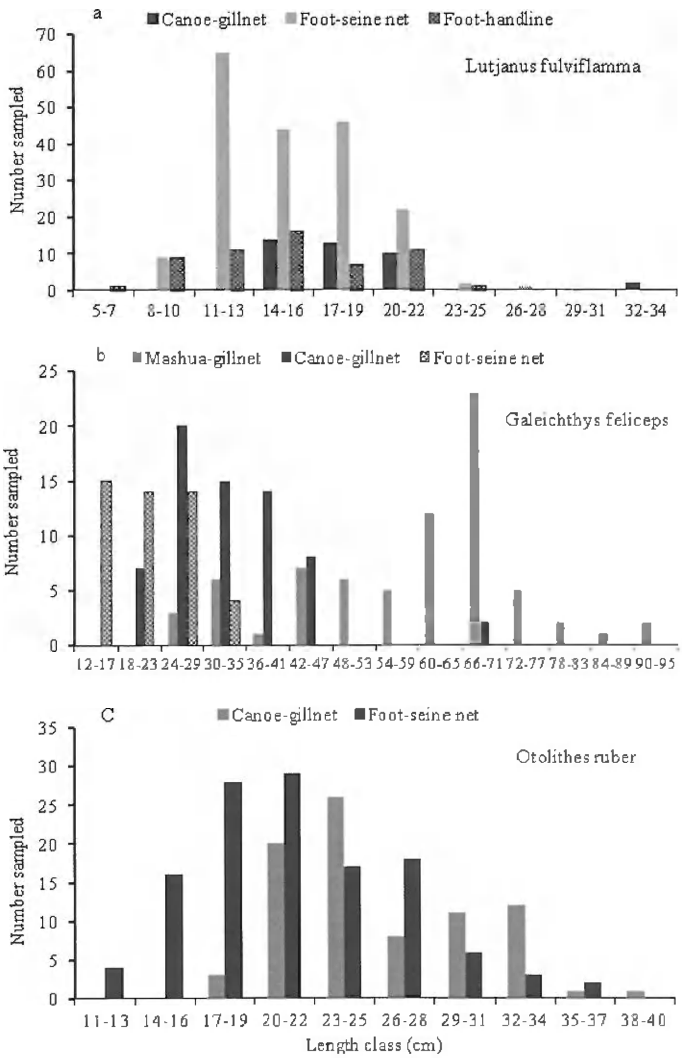

Figure 7. Comparison of size distributions of *Lutjanus fulviflamma* landed by (a) canoe-gillnet, foot-seine net and foot-handline; *Galeichthys feliceps* landed by (b) mashua-gillnet, canoe-gillnet and foot-seine net; and *Otolithes ruber* landed by (c) canoe-gillnets and foot-seine net in the Malindi-Ungwana Bay, Kenya.

From the 5 vessel-gear categories, 3 (*mashua*-gillnet, *mashua*-handline and foot-handline) recorded higher mean trophic levels during the SEM season, and 2 (canoe-gillnet and foot-seine net) recorded higher mean trophic levels during the NEM season (Fig. 8). During the SEM season, the *mashua*-gillnet recorded the highest mean trophic level (4.0 ±

0.08) of finfish landings and the foot-seine net and canoe-gillnet recorded the lowest mean trophic level of 3.2 ± 0.08 and 3.4 ± 0.07 during the SEM season respectively. There was a highly significant difference in mean trophic levels of finfish landings between the vessel-gear categories but not between the seasons (Df = 4; Err Df = 4920; F = 146.470; $p < 0.001$ and Df = 1; Err Df = 4920; F = 3.550; $p = 0.059$ respectively). There was also a highly significant effect due to vessel-gear category with season interaction (Df = 4; Err Df = 4920; F = 18.570; $p < 0.001$). Results of post hoc pair-wise comparison confirmed mean trophic levels during the SEM season from both the foot-seine net and canoe-gillnet significantly differed from those of the NEM season, and from the rest of vessel-gear categories during both the seasons ($p < 0.05$). A stronger positive correlation of mean trophic level with mean fish length by vessel-gear combination was recorded for the SEM season ($R^2 = 0.5427$) than in the NEM season ($R^2 = 0.4897$). The results of mean trophic levels however, did not consider the possibility of ontogenic diet shifts of fish species.

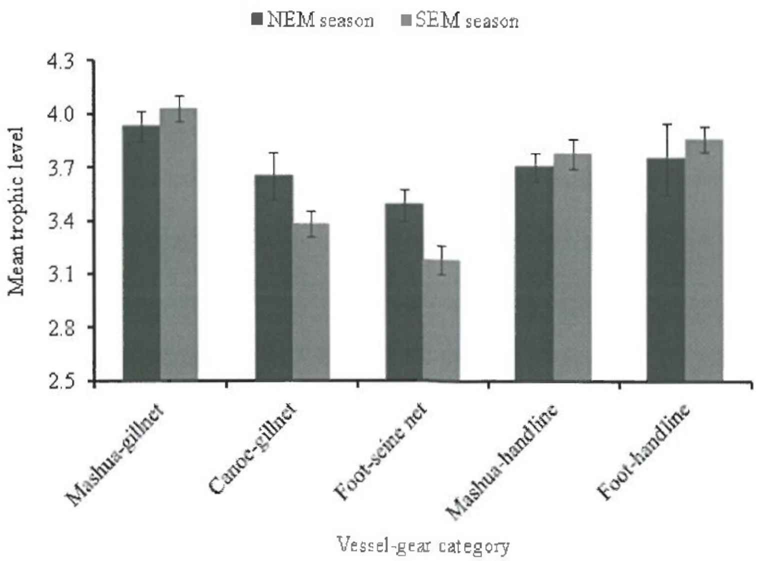

Figure 8. Mean trophic levels (± SE) of artisanal finfish landings by vessel-gear categories during the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons in the Malindi-Ungwana Bay, Kenya.

3.5. Discussion

There is a worldwide lack of reliable data on the type, dimension and quantity of fishing gear needed for accurate assessment of fishing effort in tropical coastal artisanal fisheries. Even if they exist, they are unsystematically monitored and recorded making detailed analysis difficult (Farrugio et al., 1993; Colloca et al., 2004; Battaglia et al., 2010). The quantification of fishing effort is complex given the high diversity of vessel and fishing gear types characterising the artisanal fisheries (Staglicic et al., 2011). Artisanal fisheries assessment in the past, has been mainly based on the number of boats and fishers, and this has a limitation for the evaluation of the actual fishing pressure on the resources (Salas, 2007). The categorisation by vessel-gear in this study, therefore provides a more systematic assessment of the artisanal fisheries and generates more reliable data and information for accurate decision making.

A more indepth research with longer term catch data would provide a more comprehensive understanding of artisanal fishing activities and the impact on resources. However, such an approach is not easy to implement (Staglicic et al., 2011). Given so many species, such complex and diverse habitats, so many fishers, vessel and gear types, landing sites and the impact of seasonality, it would require significant, continuous funding, trained personnel for collecting and processing data and giving recommendations for more reliable management initiatives (Staglicic et al., 2011). The short term solution to this according to Staglicic et al., (2011) is to build on the available data, like the one for Malindi-Ungwana Bay in Kenya, while relying on the knowledge of the local fishers on the biology and ecology of fish as well as socio-economic value of the fisheries that is critical for effective management (Castello et al., 2009).

The 178 finfish species from a total of 4,269 individuals sampled in this study is typical of a multigear tropical artisanal fishery that is non-selective, as evidenced by the high diversity of species landed. Whilst fishers have preferences for certain species, any available fish will be taken and only a few are considered inedible (Mangi and Roberts, 2006; Davies et al., 2009). Higher numbers of fish species caught by the canoe-gillnets and *mashua*-gillnets in this study, was attributed to the use of nets of various mesh sizes ranging between less than 2.5 inches to over 10 inches (Government of Kenya, 2012). Canoes and *mashua* also have the advantage of access to various fishing grounds with a comparative longer duration of sea time than fishers using foot. Apart from using undersized mesh sizes, different types of gillnets such as monofilament are illegal by law (Government of Kenya, 1991). Monofilaments are non-biodegradable and would continue catching fish as 'ghost gear' incase of loss of such fishing nets. In this study, the smallest sized individuals were associated with the foot-seine nets, and the largest individuals were landed by the *mashua*-gillnet. The use of foot-seine nets is restricted in shallow depths coupled with undersized mesh sizes of less than the legalised 2.5 inches. Contrary, the *mashua*-gillnets are associated with relatively offshore fishing with bigger mesh sizes of more than 6 inches (Government of Kenya, 1991). Beach seine, a type of seine net, has been associated with the smallest sized and immature individuals (McClanahan and Mangi, 2004; Davies et al., 2009). In this study, beach seines were not included since they are illegal by law due to their destructive nature both to the environment and the associated loss of biodiversity. Foot-seine net should be controlled so as to minimise the fishing pressure especially in nearshore critical habitats that are likely to be nursery grounds of fish species.

On the other hand, the *mashua*-handlines and foot-handlines were associated with the lowest numbers of fish species caught. This is a clear indication of species and size selectivity by these vessel-gear categories and are therefore potentially more suitable in sustaining the artisanal fisheries in Malindi-Ungwana Bay if they are well managed. Also the area of operation of these vessel-gears influences their composition in finfish landings. *Mashua*-

handlines and *mashua*-gillnets are mostly used by the commercial artisanal fishers capable of accessing deeper and relatively more offshore fishing grounds using the larger *mashua* wooden crafts that are propelled either by sails or outboard engines, and capable of staying at sea for a few hours to several days (pers. comm.). In this study, specific size selectivity was shown in canoe-gillnets for larger *Lutjanus fulviflamma* and *Otolithes ruber* individuals, and in *mashua*-gillnets for larger *Galeichthys feliceps* individuals. Although there was no significant differences between vessel-gears and seasons for total number of species expected in every ten individuals sampled, differences were outstanding in catch-per-unit-effort (CPUE), fish sizes and mean trophic level between the different vessel-gear categories. In this study relatively higher CPUE was associated with the *mashua*-gillnet and canoe-gillnet and relatively lower for foot-handline and foot-seine net, which is comparable with findings by Teh et al., (2009) in a survey of CPUEs in Fiji's inshore artisanal fisheries, where gillnets had the highest CPUE of 19 – 32 kg/set, and much lower for handlines with CPUE of 1.4 ± 0.3 kg/fisher.hr.

The differences in finfish compositions exhibited by the different vessel-gears is due to differences in mesh sizes between the fishing gear as well as different fishing grounds accessible by vessels. Seasonal differences in finfish compositions of the vessel-gear is likely attributed to the variability and accessibilty of the fishing grounds in different seasons of the year, and fishing frequency by the fishers. During the northeast monsoon (NEM) season, both the *mashua* and canoes are capable of accessing relatively far offshore fishing grounds as the sea is calm and therefore navigation and fishing operations using gillnets and handlines is possible, coupled with longer duration at sea. On the other hand, during the southeast monsoon (SEM) season, the sea is rough making offshore navigation and fishing impossible. During this season, fishers use specific fishing grounds that are protected from the strong waves, and normally sea time during this season is reduced. However, frequency of fishing is reportedly higher for fishers using the bigger *mashua* crafts than those using foot or smaller canoes during this bad weather (Hoorweg et al., 2008). The seasonal differences in species composition is also species specific in that some species become more abundant in certain seasons of the year (Table 4).

Mean trophic levels indicate the status of resource exploitation. The landings of *mashua*-gillnet associated with relatively large wooden crafts and nets (either set or drift gillnets) exploited finfish species with highest trophic levels and this was positively correlated with big fish size. Such fish species were mostly carnivorous large pelagics compared to the lowest mean trophic levels associated with the canoe-gillnet and foot-seine net which targeted species lower in the food chain, mostly demersals. Over-exploitation especially on reef species has resulted to lower mean trophic levels. Davies et al., (2009) reported a lowest mean trophic level of 2.6 for spear gun, and a highest of 3.67 for longline in the south-west Madagascar inshore artisanal fisheries. Other inshore fisheries have recorded much lower mean trophic levels than the one reported for Malindi-Ungwana Bay, Kenya in this study. For example, the southern Kenya artisanal reef fishery recorded a mean trophic level of between 2.6 – 2.9 (McClanahan and Mangi, 2004), south-west Madagascar artisanal fishery with 2.6 – 3.38 (Davies et al., 2009), and the Papua New Guinea artisanal fishery with 2.8 – 3.7 (McClanahan and Cinner, 2008). These values therefore, are a clear indication that, in comparison with the other artisanal fisheries, the Malindi-Ungwana Bay fishery can be described as relatively low exploited artisanal fishery. The mean trophic level values calculated for the different vessel-gear categories in this study could be monitored over time, and the reduction of these values would signify the phenomenon of fishing down the web as described by Pauly et al., (2001).

In conclusion, the multispecies, multigear and multifleet characteristic of tropical artisanal fishery make it difficult to manage fisheries resources. Therefore, there is need to identify combination of specific vessel-gear categories for generating more reliable indices that can be used to provide management recommendations instead of the traditional gear-based management strategy. This study therefore, singles out the *mashua*-gillnet for landing the highest mean trophic level and largest individuals, canoe-gillnet for landing the highest total number of species, and foot-seine net for landing the smallest individuals as suitable units for monitoring of the artisanal fisheries in Malindi-Ungwana Bay. While total annual artisanal landings have been reported to be higher in the NEM season than SEM season (Ochiewo, 2004), CPUE may not necessarily follow the same trend as observed in this study.

Acknowledgements

This study would not have been possible without the financial support awarded to the first author (CNM) by the VLIR ICP PhD program in association with the Gent University, Belgium. The involving field work for this study was ably conducted by experienced fisheries technicians and my colleagues at KMFRI, namely: James Gonda, Boaz Orembo, Dickson Odongo and Rashid Anam with vast knowledge and experience in fish identification, and are hereby much appreciated. Finally, we thank the Director, Kenya Marine and Fisheries Research Institute (KMFRI) for provision of office transport during the entire study period.

Photo credit: C.N. Munga, 2011 onboard the trawler FV Vega off the Malindi-Ungwana Bay, Kenya.

Chapter 4

4. Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys

Cosmas N. Munga[1,4*], Stephen Mwangi[1], Harrison Ong'anda[1], Renison Ruwa[1], Julius Manyala[2], Johan C. Groeneveld[3], Edward Kimani[1], Ann Vanreusel[4]

[1]Kenya Marine and Fisheries Research Institute, P.O. Box 81651 – 80100 Mombasa, Kenya.

[2]University of Eldoret, Department of Fisheries and Aquatic Sciences, P.O. Box 1125 – 30100 Eldoret, Kenya.

[3]Oceanographic Research Institute, 1 King Shaka Avenue, Durban, South Africa.

[4]Gent University, Marine Biology Research Group, Krisjgslaan 281 – S8, 9000, Gent, Belgium.

Modified from,

Cosmas N. Munga, Stephen Mwangi, Harrison Ong'anda, Renison Ruwa, Julius Manyala, Johan C. Groeneveld, Edward Kimani, Ann Vanreusel. (2013). Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys. *Fisheries Research* 147: 93–102.

4.1. Abstract

The species composition, distribution patterns and abundance of penaeid shrimps (prawns) in Malindi-Ungwana Bay, Kenya, were investigated after six years of bottom trawling ban in the area. Two surveys undertaken during the dry Northeast Monsoon (NEM) and wet Southeast Monsoon (SEM) seasons in 2011 identified areas with abundant shrimps near the outflows of the Sabaki and Tana rivers. Distinct species composition and abundance patterns were found at the two areas, attributed mainly to depth, turbidity and season. *Penaeus semisulcatus* was more abundant at the Sabaki area, where it was deeper with a muddy bottom and less turbid waters. *Fenneropenaeus indicus* was more abundant in the Tana area, a shallower, more turbid area with sandy-mud sediments. *Penaeus monodon*, *Penaeus japonicus* and *Metapenaeus monoceros* were found in both areas, suggesting wider tolerance to environmental conditions. Shrimp total biomass and catch rates were significantly higher during the SEM survey, and decreased as depth increased beyond 10 m. Small-sized *M. monoceros* and *P. monodon* individuals were abundant during the SEM survey, whereas large ones with ripe and spent gonads were more common during the NEM survey. Seasonal patterns in gonad maturity were less clear for *F. indicus* and *P. semisulcatus*. The length at first maturity (L_{50}) varied among species, suggesting that different species in the bay start spawning at different sizes, an important biological reference for sustainable resource exploitation. This study confirms the importance of the Sabaki and Tana areas being important for penaeid shrimps in Malindi-Ungwana Bay.

Key words: Penaeid shrimp; Catch composition; Abundance; Distribution; Malindi-Ungwana Bay; Kenya.

4.2. Introduction

The penaeid shrimps (or prawns) have a world-wide distribution in the tropical and subtropical seas, where they constitute an important exploitable resource in estuarine and coastal habitats (Garcia and le Reste, 1981). At least 19 species from 7 genera have been reported from the Western Indian Ocean (WIO) region (Holthuis, 1980; de Freitas, 2011), where they support artisanal and industrial shrimp trawl fisheries along the eastern coast of Africa and in Madagascar (Teikwa and Mgaya, 2003; Gillett, 2008; Le Manach et al., 2011).

Most shrimp fishing in Kenya takes place in Malindi-Ungwana Bay (Fig. 1), where two fishing sectors are active: an artisanal fishery comprising about 3500 fishers and a fleet of roughly 600 traditional fishing crafts used to catch finfish and shellfish (Fulanda et al., 2011); and a commercial bottom trawl fishery. Annual fish and shrimp landings from the artisanal fishery in this area ranged between 1013 and 1653 t between 2001 and 2008, with shrimps representing between 71.5 and 187.1 t of the landings (Munga et al., 2012a). The commercial bottom trawl fishery in the bay was initiated after a series of successful surveys undertaken by the Kenya Government, UNDP and FAO since early 1960 (Iversen, 1984; Venema, 1984; Saetersdal et al., 1993). Bottom trawling with a fleet of three or more trawlers continued for several decades, landing an average of 400 t of shrimps per year in the 1970s, 80s and 90s (Mwatha, 2005). The trawl fishery was, however, banned by the Kenyan Government in 2006, as a result of user conflicts between trawl and artisanal fishers, and declining catches (Fulanda et al., 2009, 2011; Munga et al., 2012a).

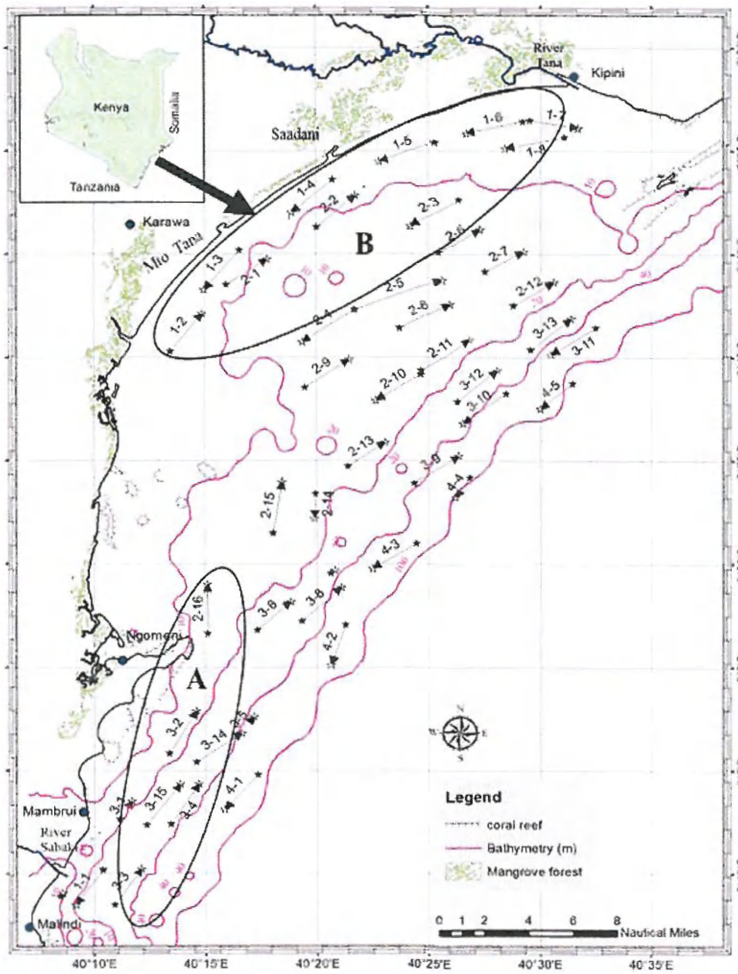

Figure 1. A map of Malindi-Ungwana Bay, Kenya, showing the groupings of trawl transects at the Sabaki (area A) and Tana (area B). Figures on the map indicate transect number and depth stratum respectively. Transect 1-2 means transect No. 1 in depth stratum 2. Transect 1-1 was incomplete and hence excluded from the survey data.

Shrimp catches in the bay comprise mainly five species: *Fenneropenaeus indicus* (formerly known as *Penaeus indicus*), *Penaeus monodon*, *P. semisulcatus*, *P. japonicus* and *Metapenaeus monoceros* (Iversen, 1984; Mwatha, 2005; Munga et al., 2012a). The post-larvae of these species prefer estuaries or estuarine-like environments, and juveniles migrate from the estuaries to shallow offshore mud banks where they grow to maturity and spawn

(Garcia and le Reste, 1981; Dall et al., 1990). Post-larvae move back into the estuarine nursery grounds from the adult breeding grounds to complete their life cycle. The life span of most penaeids is between 1 and 2 years and their abundance and mean size on offshore banks may vary greatly by depth and between seasons, reflecting spawning, recruitment, population age structure and catchability (Garcia and le Reste, 1981; Dall et al., 1990; Bishop and Khan, 1991).

A major difference between closely related shrimp species is that they prefer different habitats along gradients of substrate type, depth, turbidity, temperature and salinity (Garcia and le Reste, 1981; Dall et al., 1990). Substrate preference by juveniles tends to be maintained in the adult phase. Furthermore, movement and dispersal of post-larvae in estuarine environments involve specific sets of behavioural cues and responses, which are associated with a particular developmental period, and can be species-specific (Forbes and Benfield, 1986a, 1986b; Benfield et al., 1989; Dall et al., 1990). These differences in environmental variables may lead to differences in species composition of penaeid shrimps (Demetriades and Forbes, 1993).

Two major rivers, Tana (850 km long) and Sabaki or Athi/Galana (650 km) drain into Malindi-Ungwana Bay from the Kenyan highlands. The estuaries and nearshore mud banks with terrigenous sediments support the bulk of the shrimp fishery in the bay (Abuodha, 2003; Kitheka et al., 2005). The productivity of the bay is influenced by the river and nutrient discharge, as well as patterns of monsoon winds, tides and the offshore Somali and East African Coastal currents (McClanahan, 1988; Kitheka et al., 2005; Bouillon and Dehairs, 2007). The river discharge is highest during the wet Southeast Monsoon (SEM) season between April and October. The Northeast Monsoon (NEM) season, between November and March, receives less rain, and hence river discharge is reduced during these months. However, the influence of the sediments and the freshwater discharge by the Tana and Sabaki river systems on the bay remain poorly understood (Kitheka et al., 2005; Bouillon and Dehairs, 2007; Bouillon et al., 2009).

The aims of this study were to investigate the spatial and temporal patterns in the composition of the shrimp communities and the population structure of the dominant shrimp species in Malindi-Ungwana Bay, and to identify the importance of a suite of environmental variables on the observed patterns. Shrimp population structure (size composition, size at first maturity, and gonad maturity stages) was used to assess differences in recruitment and breeding periods between species. Spatio-temporal information on shrimp populations in Malindi-Ungwana Bay is important for the development of fisheries management strategies to ensure sustainability, while avoiding resource user conflicts between trawl and artisanal fishing sectors.

4.3. Materials and methods

4.3.1. Survey design

Malindi-Ungwana Bay lies along the northern coast of Kenya (2°30′–3°30′ S; 40°–41° E) and has an estimated trawlable area of 5,824 nm² (Iversen, 1984; Fulanda, 2003) (Fig. 1). Two surveys of 13 days duration were conducted during January–February 2011 (NEM season) and May–June 2011 (SEM season). The bay was sub-divided into 4 depth strata and the surface area of each was estimated from the British Admiralty Naval Chart No. 3362 (1957) using regular polygons: 0 – 10 m depth (137.3 nm²), 10 – 20 m (234.1 nm²), 20 – 40 m (136.3 nm²) and 40 – 100 m (38.7 nm²). A commercial bottom trawler (FV Vega, 25 m length, 146 t gross register tonnes and 496 hp engine capacity) was used to conduct the surveys by towing a net with a total length of 44.3 m, mesh sizes of 70 mm in the body and 45 mm in the cod-end, and a head rope length of 22.5 m over the stern (deeper or rocky strata) or on port or starboard booms (shallow strata). Tows were conducted roughly parallel to the shoreline, for 1 hr at a speed of 2.5 knots. The geographical coordinates and depth at the start and end of each tow were recorded. Tows were conducted near the outflows of the Sabaki (area A) and Tana (area B) rivers and further offshore areas A&B in depths up to 100 m (Fig. 1). Only catches along transects from area A and B contained shrimps in one or both seasons. These transects are therefore further considered in the data analysis. All other transects had no shrimps.

4.3.2. Sampling methods

A niskin bottle was used to collect bottom water samples for salinity and temperature measurements. From these water samples, sub-samples of at least 3 replicates of 50 ml each were processed for determination of Chlorophyll-a (Chl-a), dissolved inorganic nutrients (phosphates and nitrates), and biological oxygen demand (BOD) in a laboratory following standard procedures (Parsons et al., 1984). Sub-samples from the same sample do allow for replicating analytical protocols from which measurement accuracy may be deducted. A secchi disc was used to measure water transparency at the start and end of each tow, as an indication of turbidity.

All unwanted debris, plants and large organisms were first removed from catches, whereafter the remainder were sorted into fish and shrimp categories. Total catches of shrimps were weighed, a 2 kg sub-sample for large catches, and the entire catch for small catches, were frozen for species identification and further analysis in a laboratory. The FAO species identification sheets for the WIO (Fischer and Bianchi, 1984) were used to identify shrimps. The total catch of each species from each tow was calculated by multiplying the sub-sample by a raising factor derived from the sub-sample to total shrimp catch weight (see Stobutzki et al., 2001; Tonks et al., 2008). Shrimp carapace length (CL) was measured to the nearest 0.1 mm using a vernier calliper, and sex and gonad maturity stages were determined visually following King (1995).

4.3.3. Data analyses

Shrimp biomass was calculated using the swept area method (Sparre et al., 1989). The swept area (a, nm^2) or 'effective path swept' for each tow was calculated as:

$$a = D \times h \times X$$

where D is the distance covered in nm ($D = 60 \times \sqrt{(Lat_1 - Lat_2)^2 + (Lon_1 + Lon_2)^2 \cos 0.5^2 (Lat_1 + Lat_2)}$), h is the length of the head-rope (m), and X is the fraction of the head-rope length equal to the width of the path swept by the trawl (distance between ther otter boards). The value of X was set at 0.5 in this study (Pauly, 1980).

Catch rates were calculated as catch (*C*, kg) divided by the time spent trawling (*t*, hrs) and converted to catch per unit area (CPUA, kg/nm^2 = biomass b per unit area) by dividing by the swept area ($(C/t) / (a/t) = C/a$).

Total biomass (*B*, kg) was calculated from:

$$B = \frac{\overline{(C/a)} \times A}{X_1}$$

where *C/a* is the CPUA of all tows (kg/nm^2), A is the overall area under investigation (nm^2), and X_1 is the estimated proportion of shrimps present in the area swept. We assumed that all shrimps in the path of the tow would be captured (i.e. $X_1 = 1$). The total shrimp biomass for the surveyed area was calculated from 41 tows made in the NEM season (representing an area of 546.4 nm^2) and from 36 tows in the SEM season (507.7 nm^2).

The multivariate non-metric Multi-dimensional scaling (MDS) technique was used to identify if geographical areas (Tana and Sabaki), depth strata (per 10 m depth interval) and seasons (NEM and SEM) differed in shrimp community composition based on Bray-Curtis similarity using PRIMER v6 software (Clarke and Warwick, 2001). The spatio-temporal differences were further analysed by 2-way crossed ANOSIM with area or depth and season as factors. Two-way SIMPER analysis identified which shrimp species were most influential to the dissimilarity. Canonical Correspondence Analysis (CCA) using CANOCO v4.5 software was used to relate shrimp abundance to the environmental variables for the NEM survey only, because environmental data were not available for the SEM survey. Differences in environmental variables between areas and between depth strata for the NEM survey were tested using 1-way ANOVA, and differences in shrimp catch rates and biomass (catch-per-unit-area, CPUA) between depth strata and between seasons were tested using 2-way ANOVA from STATISTICA v7 software. Chi-square (χ^2) goodness of fit test (Zar, 1999) was used to compare sex ratios by season and area. A paired t-test was used to determine difference in sizes of shrimps between seasons. The length at first maturity (L_{50}) was determined using unsexed shrimp individuals in gonad maturity stages I and II (immature) and III, IV and V (mature) (King, 1995) by calculating the proportion of the mature individuals for each length class. The percentage mature by length class was fitted to a logistic function using least-squares and the solver routine on Microsoft Excel. The equation used was:

$$P(l) = \frac{1}{1 + e^{-(a+bl)}}$$

where $P(l)$ is the proportion of mature individuals at length l, and a and b the parameters of the logistic equation. The size at which 50% of individuals became mature was determined by back-calculation (King, 1995).

4.4. Results

4.4.1. Shrimp distribution, composition and abundance

From a total of 41 tows in the NEM survey, only 14 contained shrimps, and from 36 tows in the SEM survey, 15 contained shrimps. The MDS plots for the two surveys combined showed a distinct separation of species composition by geographical area (2-way ANOSIM: $R = 0.708$; $p = 0.001$; Fig. 2a) and by depth (2-way ANOSIM: $R = 0.539$; $p = 0.001$; Fig. 2b), but not by season (2-way ANOSIM: $R = 0.040$; $p = 0.193$; Fig. 2c). Pair-wise comparison tests indicated that species composition at 0-10 m depth differed significantly from those at 10-20 m and 20-40 m ($R = 0.337$; $p = 0.002$ and $R = 0.970$; $p = 0.001$ respectively), and that composition at 10-20 m differed from 20-40 m ($R = 0.248$; $p = 0.047$).

The difference in shrimp composition between areas was due to more abundant *P. semisulcatus* in area A (Sabaki; on average 82.2%), and more abundant *F. indicus* in area B (Tana; 52.8%; Table 1). By area, *P. semisulcatus* contributed the highest dissimilarity (36.6%) and *F. indicus* followed with 26.9%. The least contributing species to the dissimilarity were *M. monoceros*, *P. monodon* and *P. japonicus* (12.5%, 5.1% and 1.8% respectively). Two-way SIMPER analysis based on depth and season indicated that *F. indicus* was most abundant in 0-10 m (66.2%) and *P. semisulcatus* in 20-40 m depth (81.1%). Neither *F. indicus* nor *P. japonicus* were recorded at 20-40 m depth.

Seasonal differences in shrimp species composition were less pronounced for *P. semisulcatus*, *F. indicus* and *P. japonicus* (Table 1). *Metapenaeus monoceros* was more abundant during the SEM and *P. monodon* during the NEM season (Table 1). The seasonal dissimilarity depended mostly on *F. indicus* (14.6%), followed by *M. monoceros* (11.8%) and *P. semisulcatus* (10.4%). *Penaeus semisulcatus* contributed on average 90% (NEM) and 72% (SEM) by numbers to catches in area A, followed by *M. monoceros* (6% in NEM and 25% in SEM) (Fig. 3). All five penaeid shrimp species were recorded in area B in both seasons; *F.*

indicus contributed 60% (NEM) and 48% (SEM), followed by *M. monoceros* (16% and 29%). *P. japonicus* was the least abundant, irrespective of area, depth or season (Fig. 3).

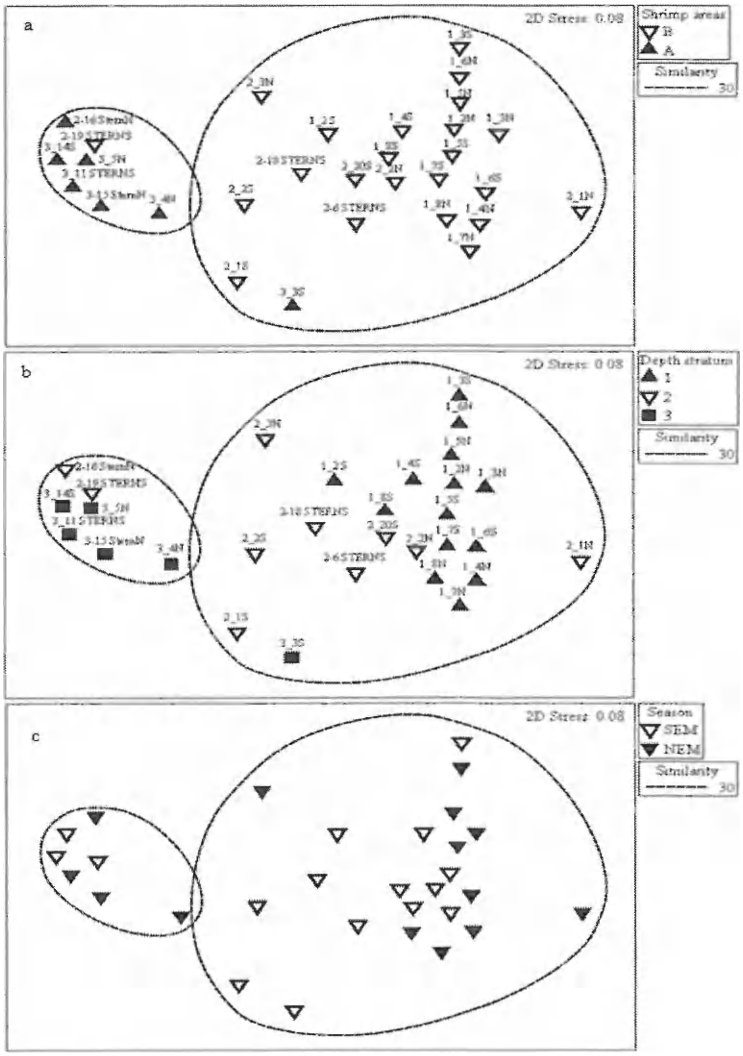

Figure 2. Non-metric MDS plots (with indication of similarity levels of 30) showing the composition of shrimps by (a) area, (b) depth stratum and (c) season in the Malindi-Ungwana Bay, Kenya, based on shrimp species abundance for the combined Northeast Monsoon (NEM) and Southeast Monsoon (SEM) surveys.

Table 1. Two-Way SIMPER Analysis: Shrimps species contributing to the dissimilarity in terms of abundance (%) by area (area A = Sabaki; area B = Tana) and by season (NEM = Northeast Monsoon survey; SEM = Southeast Monsoon survey) levels. The average dissimilarity was 82.9% and 45.7%, respectively.

Species	Areal Analysis				Seasonal Analysis			
	Abundance (avg. %)		Dissim. (avg. %)	Contrib. (%)	Abundance (avg. %)		Dissim. (avg. %)	Contrib. (%)
	Area A	Area B			NEM	SEM		
Penaeus semisulcatus	82.2	12.2	63.6	44.2	29.3	27.8	10.4	22.8
Fenneropenaeus indicus	0.0	52.8	26.9	32.4	42.6	38.7	14.6	31.9
Metapenaeus monoceros	13.9	23.4	12.5	15.0	13.3	28.1	11.8	25.8
Penaeus monodon	2.3	9.1	5.1	6.2	11.1	4.4	6.6	14.5
Penaeus japonicus	1.6	2.5	1.8	2.2	3.7	1.1	2.3	5.0

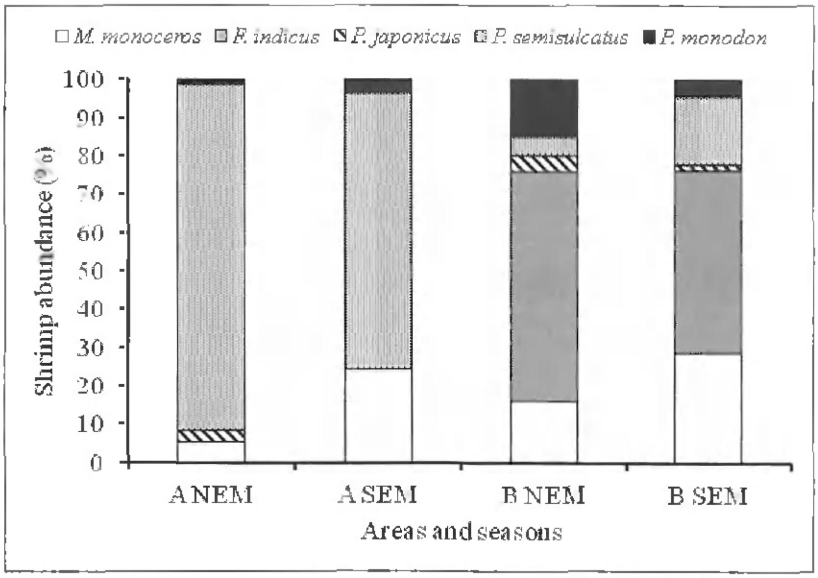

Figure 3. Relative abundance (%) of shrimp species by area (A = Sabaki; B = Tana) and season (NEM = Northeast Monsoon season; SEM = Southeast Monsoon season) in Malindi-Ungwana Bay, Kenya.

The combined data for all shrimp species, including both seasons and all depths shallower than 40 m, indicated that shrimps were more abundant in the Tana area (3.76 kg/h) than in the Sabaki area (0.82 kg/h). The overall shrimp catch rate and biomass during the SEM (6.17 kg/h and 460.7 kg/nm^2) were higher than during the NEM survey (1.45 kg/h and 136.5 kg/nm^2; Table 2). In both surveys, biomass was greatest at the shallowest depth (0-10 m), and no shrimps were caught deeper than 40 m (Table 2). Results of 2-way ANOVA indicated that shrimp catch rates and biomass differed significantly between depths and seasons, and that the effect of the depth-season interaction was insignificant (Table 3).

Table 2. Shrimp catch rates (mean ± SE) and total biomass by depth stratum estimated from the bottom trawl surveys undertaken during the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) season in Malindi-Ungwana Bay, Kenya. A dash means that no catch was recorded.

		Northeast Monsoon survey (NEM)			Southeast Monsoon survey (SEM)		
Depth (m)	Area (nm^2)	Hauls (n)	Catch rate (kg/h)	Biomass (kg/nm^2)	Hauls (n)	Catch rate (kg/h)	Biomass (kg/nm^2)
0-10	137.3	7	6.34 ± 1.72	433.5	7	16.85 ± 3.80	1156.8
10-20	234.1	16	0.66 ± 0.45	48.2	19	5.19 ± 2.43	373.2
20-40	136.3	13	0.36 ± 0.26	27.6	10	0.56 ± 0.50	40.4
40-100	38.7	5	-	-	-	-	-
Overall	546.4	41	1.45 ± 0.49	136.5	36	6.17 ± 1.73	460.7

Table 3. Results of 2-way ANOVA showing significant differences in shrimp catch rates (kg/h) and biomass (kg/nm2) between seasons, depth strata and the interaction of season and depth stratum, in Malindi-Ungwana Bay, Kenya.

			Catch rate (kg/h)		Biomass (kg/nm^2)	
Factors	Df	Error Df	F	p-value	F	p-value
Season	1	23	9.138	***0.006***	8.531	***0.008***
Depth stratum	2	23	4.397	***0.024***	3.872	***0.036***
Season *Depth stratum	2	23	1.748	0.197	1.670	0.210

4.4.2. Environmental measurements and species associations

Water depth of the trawled area was significantly greater at the Sabaki (area A) than the Tana (area B), but turbidity was greater at the Tana area (Table 4). No significant difference was observed in salinity, dissolved oxygen, dissolved inorganic nutrients (phosphates and nitrates), chlorophyll-a, or biological oxygen demand of bottom water samples collected from the two areas (Table 4). Turbidity decreased with increasing depth stratum from 0-10 m to 40-100 m, and this can be interpreted as a decrease in turbidity with increasing distance from the shore and the river outflows.

Results of CCA (Fig. 4) showed that axis 1 explains up to 68.5% of the species-environment associations. The distribution of *P. semisulcatus* was positively correlated to deeper and less turbid waters, and the rest of the shrimp species were negatively correlated to these environmental variables. *Penaeus japonicus* was positively correlated with chlorophyll-a (Chl-a) and water temperature, *P. monodon* with dissolved oxygen (DO), and *M. monoceros* with nitrates. While *F. Indicus* was negatively correlated with BOD.

Table 4. Environmental variables (mean ± SE) by area and depth stratum measured during the Northeast Monsoon (NEM) survey in Malindi-Ungwana Bay, Kenya, (data not available for Southeast Monsoon, SEM survey). Measurements are for bottom water, except for turbidity (Secchi depth, m). Area A = offshore of Sabaki River; Area B = offshore of Tana River. Df = 2 for area analyses. Df = 3 for depth analyses.

Environmental variable	Area and depth categories				ANOVA	
By area	Area A	Area B	A&B offshore		F	p-value
Water depth (m)	34.0 ± 6.2	8.4 ± 1.0	26.4 ± 3.9		13.160	***<0.001***
Water Temp. (°C)	27.9 ± 0.2	28.1 ± 0.3	27.1 ± 0.2		6.250	***0.005***
Salinity (‰)	36.3 ± 0.3	36.4 ± 0.2	36.4 ± 0.1		0.090	0.914
Secchi depth (m)	13.8 ± 1.6	2.1 ± 0.5	11.3 ± 0.7		31.690	***<0.001***
Dissolved Oxygen (mg/l)	5.4 ± 0.2	5.5 ± 0.1	5.6 ± 0.1		0.100	0.320
Chlorophyll-a (µg/l)	0.24 ± 0.1	0.32 ± 0.1	0.29 ± 0.0		0.010	0.821
(Nitrate + Nitrite)-N (µM)	1.2 ± 0.4	1.7 ± 0.3	1.2 ± 0.1		0.690	0.201
Phosphates-P (µM)	1.4 ± 0.4	1.1 ± 0.1	0.9 ± 0.1		1.410	0.259
BOD_{5days} (mg/l)	4.4 ± 0.4	4.7 ± 0.11	4.2 ± 0.1		2.060	0.145
By depth stratum	0-10 m	10-20 m	20-40 m	40-100 m	F	p-value
Water Temp. (°C)	27.7 ± 0.2	27.2 ± 0.3	27.7 ± 0.2	27.3 ± 0.2	1.000	0.408
Salinity (‰)	36.3 ± 0.2	36.4 ± 0.2	36.2 ± 0.1	37.0 ± 0.6	1.900	0.151
Secchi depth (m)	1.5 ± 0.2	8.6 ± 0.7	12.7 ± 1.2	14.0 ± 1.2	19.22	***<0.001***
Dissolved Oxygen (mg/l)	5.5 ± 0.1	5.7 ± 0.0	5.4 ± 0.1	5.7 ± 0.2	3.050	***0.043***
Chlorophyll-a (µg/l)	0.2 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.557	0.647
(Nitrate + Nitrite)-N (µM)	1.8 ± 0.4	1.3 ± 0.1	1.2 ± 0.2	0.8 ± 0.2	1.084	0.370
Phosphates-P (µM)	1.1± 0.2	0.9 ± 0.1	1.1 ± 0.1	1.2 ± 0.6	0.839	0.482
BOD_{5days} (mg/l)	4.7 ± 0.2	4.6 ± 0.1	4.1 ± 0.2	3.5 ± 0.1	5.885	***0.003***

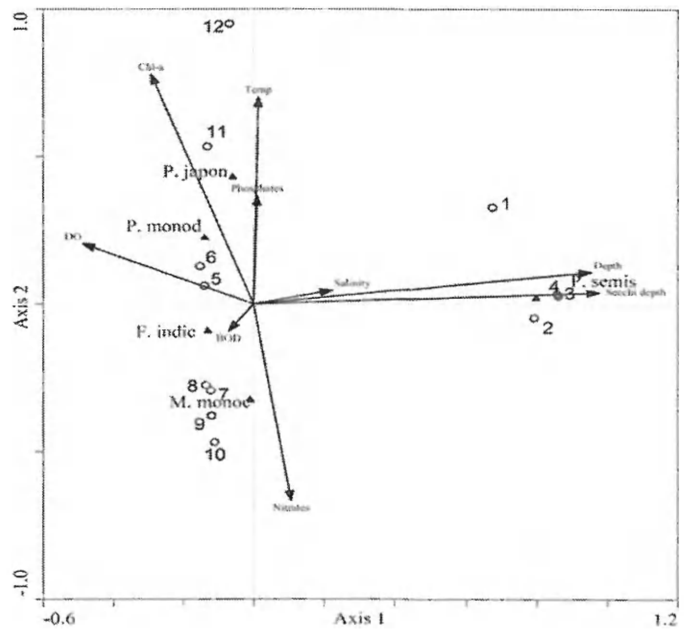

Figure 4. Results of CCA showing relative importance of individual environmental variables to shrimp distribution based on the Northeast Monsoon (NEM) survey data in the Malindi-Ungwana Bay, Kenya. Numbers are trawl transects 1-4 in area A (Sabaki) and 5-12 in area B (Tana). Axis 1 explains up to 68.5% of the species-environment associations. Environmental data for the Southeast Monsoon (SEM) survey were not available.

4.4.3. Shrimp gonad stages, size at first maturity and sex ratios

Large proportions (generally > 0.4) of *M. monoceros*, *F. indicus* and *P. semisulcatus* females had immature or developing gonads (Stages I or II) during both the NEM and SEM surveys (Fig. 5). In *P. monodon*, the bulk of female gonads were ripe (Stage IV; 0.43) during the SEM survey and spent by the NEM survey (Stage V; 0.38) (Fig. 5), and during this period their mean carapace length (CL) increased from 34.0 to 45.2 mm (Fig. 6). Most *M. monoceros* females had immature or developing gonads during the SEM survey (Stages I and II; 0.73), but by the NEM survey these were more mature (Stages III-V; 0.56) (Fig. 6). Again this pattern was consistent with an increase in mean CL, from 23.9 mm during the SEM to 31.3 mm during the NEM survey (Fig. 6). *P. semisulcatus* captured during the NEM survey were significantly smaller than those caught during the SEM survey (t-test = -2.17, $p = 0.03$) in area A (Fig. 6), and a similar pattern was observed in area B, although the difference in mean CL was not significant. More females had spent gonads during the SEM survey (Fig. 5). *F. indicus* captured during the NEM survey were also significantly smaller than those caught during the SEM survey (t-test = -5.32, $p < 0.0001$).

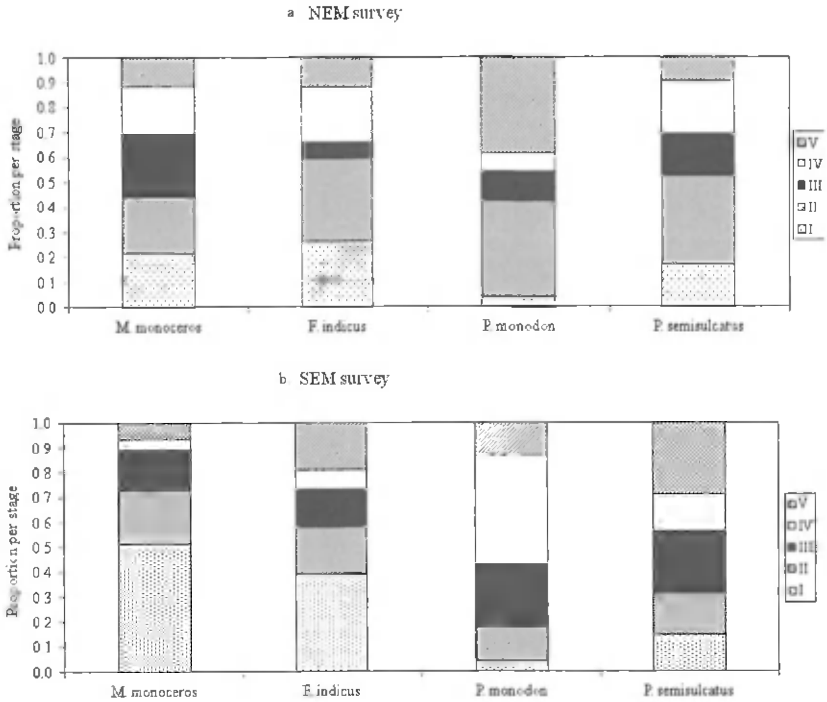

Figure 5. Proportions of female gonad maturity stages by shrimp species caught in Malindi-Ungwana Bay, Kenya, during (a) Northeast Monsoon (NEM) and (b) Southeast Monsoon (SEM) surveys. Maturity stages were categorised as: I - immature, II - developing, III – maturing, IV – ripe and V – spent.

Metapenaeus monoceros samples were dominated by females (56%), and *F. indicus* by males (64%; χ^2-tests, $p < 0.001$ in both cases), but no significant deviation from parity was observed in the other species ($p > 0.05$ in all cases) (Fig. 6). The size at first maturity (L_{50}) differed according to species (Fig. 7). *P. monodon* recorded the largest L_{50} of 41.9 mm within a sampled range of 23 to 72 mm CL. This was followed by *F. indicus* (L_{50} = 37.4 mm; 12 to 48 mm), *M. monoceros* (L_{50} = 36.0 mm; 9 to 46 mm) and *P. semisulcatus* (L_{50} = 33.4 mm; 17 to 58 mm).

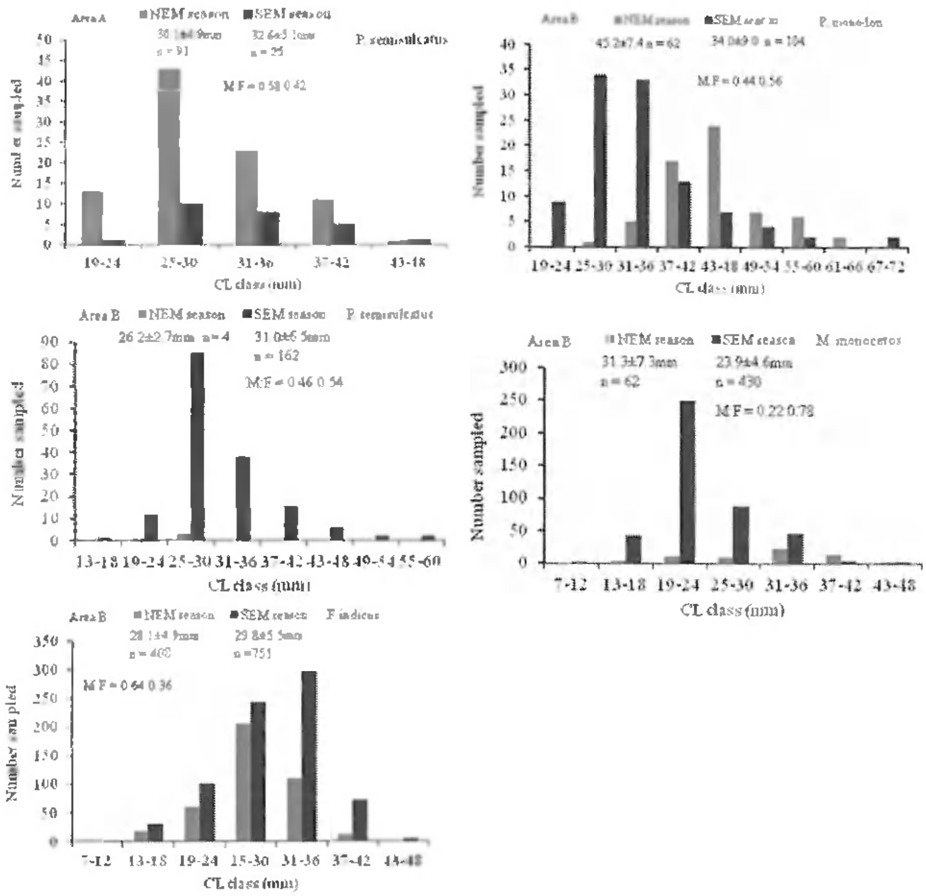

Figure 6. Spatio-temporal size-frequency distributions, mean carapace lengths, and sex ratios (seasons combined) for the most abundant penaeid shrimp species sampled during the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) surveys in Malindi-Ungwana Bay, Kenya. Only P. semisulcatus was abundant in area A (Sabaki).

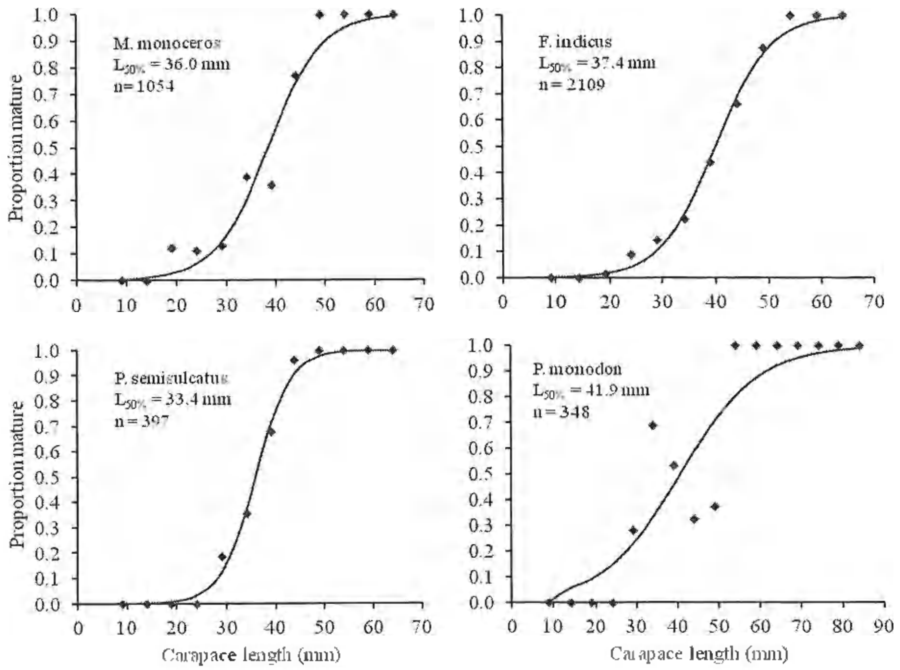

Figure 7. Maturity ogives showing L50 estimates of penaeid shrimps (sexes combined) caught in the bottom trawl surveys in Malindi-Ungwana Bay, Kenya.

4.5. Discussion

The distribution of shallow-water penaeid shrimps in Malindi-Ungwana Bay was restricted to the Sabaki and Tana areas (A and B respectively, Fig. 1), and no shrimps were caught further offshore of these areas. The species composition and abundance patterns differed between the two areas: all five shrimp species were recorded at the Tana area in both the NEM and SEM seasons, whereas only three species (*P. semisulcatus*, *M. monoceros* and *P. monodon*) were recorded at the Sabaki area during the SEM. Although some clear patterns in species composition and abundance were observed in this study, it should be taken into account that data from only two surveys were available. Therefore inferences relating to these patterns should be viewed as indicative only.

Fenneropenaeus indicus was the most abundant species at the Tana area, coinciding with the more turbid environment. Turbid waters in Maputo Bay, Mozambique also coincided with areas of high *F. indicus* catches by commercial trawlers, and turbidity also affected the distribution of *F. indicus* and *M. monoceros* at Saco da Inhaca (Macia, 2004). Juvenile *F. indicus* and *M. monoceros* inhabited turbid waters with reduced visibility to escape predators (Macia, 2004; de Freitas, 2011). *F. indicus* in the present study was not recorded in the less turbid and deeper Sabaki area.

Penaeus semisulcatus dominated shrimp catches in the Sabaki area, and previous studies from the Western Indian Ocean (WIO) region showed that this species prefers low turbidity, muddy substrates and deeper water, where it is often associated with sea grass meadows (Macia, 2004; Forbes and Demetriades, 2005; de Freitas, 2011). *P. semisulcatus* is a naturally burrowing species during daytime, but feeds during the night when it can be fished more successfully (Hughes, 1966; Vance et al., 1994; de Freitas, 1986; 2011). Post-larval and young adult *P. semisulcatus* are often associated with submerged macrophytes, especially in estuarine backwaters, and adults prefer deeper waters (3-20 m) in large bays and offshore shelf areas (de Freitas, 1986; 2011). Macia (2004) observed that *P. semisulcatus* preferred deeper water bays compared to *F. indicus*; our findings agree with this observation. *P. monodon*, *M. monoceros* and *P. japonicus* inhabited both Tana and Sabaki areas, suggesting that they have a broader tolerance to factors that may limit *F. indicus* distribution in the bay. Forbes and Demetriades (2005) also suggested that *M. monoceros* can inhabit diverse habitats, from areas with submerged macrophytes to deeper reaches of mangrove swamps in low salinity environments.

The relatively shallow depth associated with sandy bottom and high turbidity, especially during the SEM season, favoured the existence of higher shrimp biomass at the Tana, compared to the Sabaki area. Fulanda et al. (2011) and Munga et al. (2012) also reported higher shrimp catch rates at the Tana area during the SEM than NEM season, using longer term commercial bottom trawl data. Similar seasonal variation in shrimp catch rates were also reported for the Tanzanian commercial bottom trawl and artisanal shrimp fisheries (Semesi et al., 1998; Teikwa and Mgaya, 2003).

Size frequency and gonad maturity data can be used to define shrimp seasonal life cycles, which are often species-specific (Garcia and le Reste, 1981; Dall et al., 1990; Gribble et al., 2007). For example, a preponderance of small shrimps on nearshore banks may suggest a recent recruitment event, larger shrimps with mature gonads would suggest a spawning season, and large shrimps with spent ovaries would suggest that spawning had recently taken place. In a best-case scenario, a series of monthly samples spanning at least a year would be required to describe the annual cycle of recruitment, growth to maturity and reproduction. However, given the cost of bottom trawl surveys, and the spatial heterogeneity of shrimp populations, far fewer samples are generally available, and inferences are somewhat speculative.

Fenneropenaeus indicus in south-eastern Africa generally spawns throughout the year, with a peak around September to February (Benfield et al., 1989; de Freitas, 2011). Demetriades and Forbes (1993) showed that small *F. indicus* dominated catches in January to June on the Tugela Bank in South Africa, suggesting that juveniles then move out of estuaries onto offshore banks. Similarly, *F. indicus* caught in Kenya was slightly smaller during January and February (NEM survey) than in May and June (SEM survey). A fundamental difference between these two areas is that the rainy season off eastern South Africa is between October and January (Demetriades and Forbes, 1993), corresponding to the dry NEM season in Kenya. The seasonal pattern in Kenya was difficult to discern from only two surveys, especially if some spawning occurred throughout the year, and more regular annual sampling during NEM and SEM seasons will be required to clarify the seasonal cycle of *F. indicus* in this area.

The mean sizes of *M. monoceros* and *P. monodon* sampled in the SEM survey were much smaller than in the NEM survey, and a larger proportion of gonads were either ripe or spent in the latter samples (Figs. 5 and 6). This suggests that young adults of both species move away from the nearshore areas of the estuaries early in the year, during the SEM season, and grow to maturity during the dry NEM, towards the end of the year, or the beginning of the following year. It therefore appears that most *P. monodon* females spawned between the two surveys (between June and January), possibly at the end of the rainy season (SEM) or beginning of the dry season (NEM), when movement of post-larvae back to estuaries would presumably not be affected by swollen rivers. Assuming similar growth rates to maturity, and based on female gonad condition and shrimp size frequencies, it is therefore suggested that young *P. monodon* and *M. monoceros* in Kenya move out of the Sabaki and Tana estuaries onto offshore sandbanks during the wet SEM season (but possibly earlier than this), where they mature and spawn at a much larger size prior to, or during the dry NEM season. It should be noted that small *M. monoceros* (Fig. 6) and some immature *P. monodon* (Fig. 5) are also present on these banks during the NEM, suggesting that at least some recruitment from estuaries take place then. Demetriades and Forbes (1993) found a peak in catch rates of small *M. monoceros* in July to September off the Tugela Bank, and de Freitas (2011) found small *P. monodon* in Mozambique to migrate out of estuarine backwaters onto offshore banks from May onwards, with mean size on offshore banks increasing towards November. The seasonal patterns observed for *M. monoceros* and *P.monodon* in Kenya in the present study and in Mozambique (de Freitas, 2011) and South Africa (Demetriades and Forbes, 1993) therefore appear to be broadly similar, despite the different rainy seasons.

The size at first maturity (L_{50}) is commonly evaluated for wild shrimp populations as a point of biological reference, especially spawning activity (Niamaimandi et al., 2008). The L_{50} of the four most common species in the present study differed substantially, suggesting that they start spawning at different sizes. *P. monodon* achieved L_{50} at the largest size, and *P. semisulcatus* at the smallest size. The estimates in the present study were within the range of those obtained by Teikwa and Mgaya (2003) off Tanzania, and by Niamaimandi et al. (2008) in the Persian Gulf. These authors also found L_{50} to depend on sex, being somewhat larger in females, whereas our study aggregated data for both sexes.

In conclusion, shrimp abundance in Malindi-Ungwana Bay is concentrated near the outflows of the Sabaki and Tana rivers, and these two areas have distinct species compositions, with *F. indicus* dominating in the Tana area and *P. semisulcatus* in the Sabaki area. Species-environment associations showed that *P. semisulcatus* abundance was strongly correlated to deeper less turbid waters, and that the other penaeid shrimp species were negatively correlated to these variables. Total biomass decreased with increasing depth, and was higher during the SEM than the NEM season. Seasonal recruitment and spawning cycles were species-specific, but more regular samples are required to confirm suggested patterns.

Acknowledgements

This study was part of the South West Indian Ocean Fisheries Project (SWIOFP) under Component 2 (crustaceans). The first author (CNM) was financially supported by the VLIR UOS PhD program in association with the Gent University, Belgium. The KMFRI technical team, fellow researchers, captain and crew of the wet-leased trawler FV Vega are thanked for their many contributions during field work and data analyses, and Teresa Athayde is thanked for logistic support during the planning of the surveys. The Director of KMFRI and Ministry of Fisheries Development in Kenya are thanked for granting a special research licence for the surveys.

Photo credit: C.N. Munga, 2011 onboard the trawler FV Vega off the Malindi-Ungwana Bay, Kenya.

Chapter 5

5. Bottom trawl finfish bycatches in Malindi-Ungwana Bay, Kenya: Is there an overlap in resource use with artisanal fishery?

Cosmas N. Munga[1,4*], Stephen Mwangi[1], Harrison Ong'anda[1], Renison Ruwa[1], Julius Manyala[2], Johan C. Groeneveld[3], Edward Kimani[1], Ann Vanreusel[4]

[1]Kenya Marine and Fisheries Research Institute, P.O. Box 81651 – 80100 Mombasa, Kenya.

[2]University of Eldoret, Department of Fisheries and Aquatic Sciences, P.O. Box 1125 – 30100 Eldoret, Kenya.

[3]Oceanographic Research Institute, 1 King Shaka Avenue, Durban, South Africa.

[4]Gent University, Marine Biology Research Group, Krisjgslaan 281 – S8, 9000, Gent, Belgium.

5.1. Abstract

The species composition, distribution patterns and biomass of finfish trawl bycatches in Malindi-Ungwana Bay, Kenya are described from two bottom trawl experimental surveys and compared with artisanal catches to identify resource overlap. The surveys were undertaken during the dry Northeast Monsoon (NEM) season and during the wet Southeast Monsoon (SEM) season in 2011, and artisanal catches were sampled along the bay between 2009 and 2011. Trawl bycatch rates and biomass were significantly higher in inshore than offshore areas and distinct in composition but less differing between seasons. Species richness was not significantly different between areas and seasons, nor was their interaction. However, Shannon-Wiener diversity index was significantly different between the seasons but not between areas nor significant interaction. A total of 158 fish species in 61 families were identified during the NEM survey, and 161 species in 57 families during the SEM. However, only 7 families contributed for 66.6% by mass during the NEM whereas 10 families contributed for 59.7% during the SEM. Offshore trawl bycatches showed lower similarity with the composition of artisanal catches than inshore trawl bycatches. The similarity between inshore trawl bycatches and artisanal catches was mainly attributed to 7 common and most abundant artisanal target species confirming the existence of a potential but localised inshore resource use overlap, whereas these 7 species were mostly absent in offshore trawl bycatches. Furthermore, significantly smaller sized individuals of these 7 species occurred in the trawl bycatches which may affect fish recruitment when trawling is continued. Also species diversity in both inshore and offshore trawl bycatches was significantly higher than in artisanal catches further confirming the possible resource overlap between the two fishery types in the Malindi-Ungwana Bay.

Key words: Trawl bycatch; Artisanal catch; Distribution patterns; Species composition; Malindi-Ungwana Bay; Kenya.

5.2. Introduction

Bottom trawling for shrimps (prawns) has attracted increasing criticism worldwide because it catches large quantities of non-target species as bycatch, and causes resource use conflict between trawlers and other sectors such as artisanal and recreational fishers (Jones, 1992; Hall, 1996; Kaiser et al., 2002; Kelleher, 2005; Fennessy, et al., 2008). Bycatch may be retained but most is discarded at sea because of low market value and limited onboard storage space. Tropical shrimp fisheries worldwide produce an estimated 1.86 million t of discards (Kelleher, 2005), and the main shrimp trawling areas of the Western Indian Ocean (WIO) region (Sofala Bank in Mozambique; Rufiji Delta in Tanzania; Malindi-Ungwana Bay in Kenya; Madagascar coastline; and Tugela Bank in South Africa; see Olbers and Fennessy, (2007)) produce an estimated total bycatch of 120 000 t annually (Kelleher, 2005). In nearly all shrimp trawl fisheries, the bycatch proportion outweighs the shrimp catch by a factor of between 3 and 15 (Hall et al., 2000), being the highest in comparison to other bycatch quantities produced by other fishing methods. The growing importance of bycatch in the world fisheries management has been addressed since 1990s by the international ocean-oriented bodies world wide (Alverson et al., 1994), and this concern has also been reflected by the marked increase in bycatch research over the past few decades (Soykan et al., 2008). Bycatch, especially that of discards has been identified as among the several issues that challenge fisheries sustainability.

Bottom trawling for shrimps in the Malindi-Ungwana Bay started after a series of surveys during the 1960s and 1970s (Nzioka, 1979). A commercial shrimp trawl fishery with a small fleet (mostly 3 trawlers at minimum) developed thereafter and operated for more than 3 decades, but was suspended between 2006 and 2011, ostensibly as a result of resource use conflicts emanating from damage caused to artisanal gear by trawlers, and excess discarding of trawl bycatches traditionally targeted by at least 3,500 artisanal fishers in the bay

(Ochiewo, 2004; Mwatha, 2005; Fulanda et al., 2011; Munga et al., 2012a). Bycatch reduction initiatives were first introduced in the bay in early 2000s (Fennessy et al., 2004; Mwatha, 2005). These included: a seasonal closure (beginning of November to end of March every year), prohibition on nocturnal trawling, minimum trawling distance, and mandatory use of Turtle Excluder Devices (TEDs) on trawl nets, but enforcement and compliance was not effective and hence the imposition of the trawl ban afterwards (Government of Kenya, 2010b).

On the other hand, artisanal fishery in the bay is restricted to inshore fishing grounds mostly less than 3 nm due to inability of the traditional vessels to access offshore fishing grounds. However, these inshore fishing grounds, are also the main shallow water shrimp trawling grounds (Mwatha, 2005; Munga et al., 2012a; Munga et al., 2013) resulting in user conflict and a possible resource overlap between the artisanal fishery and semi-industrial bottom trawling due to excessive discarding of bycatches otherwise targeted by the artisanal fishery in the same fishing grounds.

Continued excessive discarding of bycatches in the bay, steadily coincided with a reduction in the artisanal fish landings before the trawl ban in 2006 (Munga et al., 2012a). A lower factor of 1.5 and a higher of 7.0 of retained fish bycatches outweighing the target catches (shrimps) were recorded in the bay before the ban (Fulanda et al., 2011; Munga et al., 2012a). However, bycatch proportion may have been much higher than this, as bycatch was subjectively recorded due to lack of effective enforcement. An earlier study on bycatch in the same area (Mwatha, 2005) that neither included season and area differences, nor a direct comparison with artisanal catches, recorded more than 90 different fish species of retained bycatches with the families Sciaenidae, Sphyraenidae, Sillaginidae, Scombridae, Mullidae and Pomatomidae representing the highest biomass. The discarded bycatch comprised different families mainly the Leiognathidae, Clupeidae, Dasyatidae and Carcharhinidae. These families contributed more than 43% of non-commercial fishes, whereas juveniles of some commercially important *Otolithes ruber* and *Johnius sp.* (Sciaenidae), and *Pomadasys sp.* (Haemulidae) made up 25% of discards by mass while these are also target species for the artisanal fishery (Munga et al., 2012a). Since the promulgation of the shrimp fishery management plan in 2011, reduced conflicts between the shrimp trawl and artisanal fisheries are anticipated. This management plan, however, lacks adequate scientific information to guarantee an appropriate ecosystem approach, and therefore is based on a precautionary principle.

The aim of this study was to identify and quantity finfish species that were abundant in trawl bycatches (inshore and offshore) and compare them with fish species targeted by the artisanal fishery, so as to provide specific spatio-temporal information for the eventual development of fisheries management strategies to mitigate against resource use overlap and conflicts in the bay.

5.3. Materials and methods

5.3.1. Survey design for trawl bycatches

Malindi-Ungwana Bay lies along the northern coast of Kenya (2°30′–3°30′ S; 40°–41° E) and has an estimated trawlable area of 5,824 nm^2 (Iversen, 1984; Fulanda, 2003) (Fig. 1). Two surveys of 13 days duration were conducted during January–February 2011 (NEM season) and May–June 2011 (SEM season). The bay was sub-divided into 4 depth strata and the area of each was estimated from the British Admiralty Naval Chart No. 3362 (1957) using regular polygons: 0 – 10 m depth (137.3 nm^2), 10 – 20 m (234.1 nm^2), 20 – 40 m (136.3 nm^2) and 40 – 100 m (38.7 nm^2). A commercial bottom trawler (FV Vega, 25 m length, 146 t gross register tonnes and 496 hp engine capacity) was used to conduct the surveys by towing a net with a total length of 44.3 m, mesh sizes of 70 mm in the body and 45 mm in the cod-end, and a head rope length of 22.5 m over the stern (deeper or rocky strata) or on port or starboard booms (shallow strata). Tows were conducted roughly parallel to the shoreline, for 1 h at a speed of 2.5 knots. The geographical coordinates and depth at the start and end of each tow were recorded. Tows were conducted inshore near the outflows of the Sabaki (area A) and Tana (area B) rivers and offshore (A&B) in depths up to 100 m (Fig. 1).

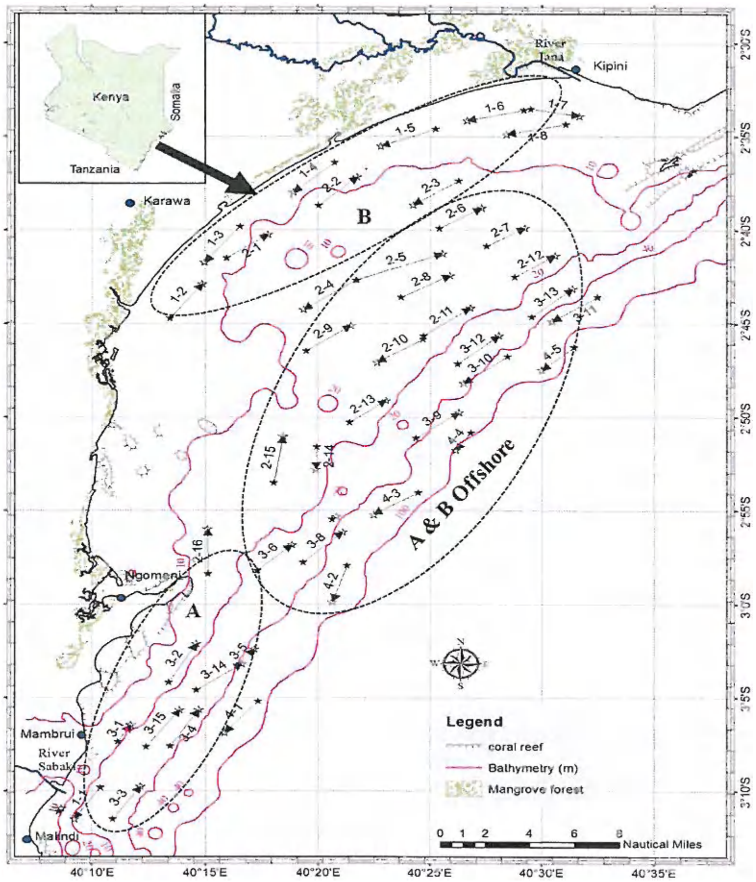

Figure 1. A map of Malindi-Ungwana Bay, Kenya, showing the grouping of trawl transects at the Sabaki (A) and Tans (B) inshore area, and offshore (area A&B). Figures on the map indicate transect number and depth stratum respectively. Transect 1-2 means transect No. 1 in depth stratum 2. Malindi, Ngomeni and Kipini were the fishing areas where artisanal catches were sampled.

5.3.2. Sampling methods

In processing the samples, all unwanted debris, plants and large organisms were first removed from the catches. Large fish were then removed, identified, weighed and lengths meausured separately. The remainder of the catch was sorted into fish and shrimp categories. All fish catches, depending on size were divided into equal proportions, and one proportion randomly taken as a representative sample. Each representative sample was weighed, individual fish species were weighed separately and individual fish total lengths (TL, cm) measured using a fixed marked ruler on a flat board. The total catch of each species from each tow was calculated by multiplying the sub-sample by a raising factor derived from the sub-sample to total fish catch weight (see Stobutzki et al., 2001; Tonks et al., 2008). Fish species identification was done by reference to Smith and Heemstra (1998), Lieske and Myers (1994) and van der Elst (1981).

5.3.3. Data collection for artisanal catches

Shore-based catch assessments were conducted in 2009 (10^{th}- 18^{th} June; 6^{th}- 7^{th} November; and 2^{nd}-4^{th} and 6^{th}- 7^{th} December), 2010 (4^{th}- 6^{th} March; 26^{th}- 30^{th} June; and 25^{th}-27^{th} September), and 2011 (3^{rd}- 14^{th} March; 20^{th}- 24^{th} July; and 22^{nd}- 26^{th} September) in three major fishing areas: Malindi, Ngomeni and Kipini located along the 200 km long Malindi-Ungwana Bay (Fig. 1) totalling 49 shore visits and 85 samples covering both the NEM and SEM seasons. At the landing sites, finfish landings were randomly examined during the day from collaborative fishers returning from fishing. Fish catch data either for the unlikely night time fishing or from uncollaborative fishers were therefore exluded. For large catches, total weight was measured using a weighing balance before a homogeneous mixture was made, and a random sub-sample taken for individual fish length measurement and total weight by species. For small catches, all fish were measured and weighed by species. Fish species identification and total length measurement were conducted as those of the trawl bycatches.

5.3.4. Data analyses for trawl bycatches

Trawl bycatch biomass was calculated using the swept area method (Sparre et al., 1989). The swept area (a, nm^2) or 'effective path swept' for each tow was calculated as:

$$a = D \times h \times X$$

where D is the distance covered in nautical miles ($D = 60 \times \sqrt{(Lat_1 - Lat_2)^2 + (Lon_1 + Lon_2)^2 \cos 0.5^2 (Lat_1 + Lat_2)}$), h is the length of the head-rope (m), and X is the fraction of the head-rope length equal to the width of the path swept by the trawl. The value of X was set at 0.5 in this study (Pauly, 1980).

Bycatch rates were calculated as catch (C, kg) divided by the time spent trawling (t, hours) and converted to catch-per-unit-area (CPUA, kg/nm^2) by dividing by the swept area ($(C/t) / (a/t) = C/a$).

Total biomass (B, kg) was calculated from:

$$B = (\overline{c/a}) \times A$$

where C/a is the CPUA of all tows (kg/nm^2), A is the overall area under investigation (nm^2). The finfish total biomass for the entire surveyed area (546.4 nm^2) was calculated from 41 tows made in the NEM season and 37 tows in the SEM season.

The multivariate non-metric multi-dimensional scaling (MDS) technique was used to identify if geographical areas (Tana-Sabaki inshore and offshore) and seasons (NEM and SEM) differed in trawl bycatch community composition based on Bray-Curtis similarity using PRIMER v6 (Clarke and Warwick, 2001). The area and seasonal differences were further analysed by 2-way crossed ANOSIM with area and season as factors. Two-way SIMPER identified which bycatch fish species were most influential to the dissimilarity or similarity.

Kruskal-Wallis non-parametric test was used to identify significant differences in trawl bycatch rates (kg/h) and biomass between areas and seasons, and differences in finfish bycatch species diversity (species richness *S* and Shannon-Wiener diversity index *H'*) between areas with seasons identified by 2-way ANOVA parametric test. These tests were done using STATISTICA v.7.

5.3.5. Data analyses for artisanal catches and comparison with trawl bycatches

Artisanal catches as analysed separately in Chapter 3 were used here for the comparison. The artisanal finfish species composition was compared to that of trawl bycatches in an MDS plot. In this and further analyses where fishery types were compared, three groups were considered: artisanal catches, inshore and offshore trawl bycatches. Two way SIMPER analysis (with season and fishery types as factors) identified the species which were responsible most for the dissimilarities and similarities. Fish size comparison for the most abundant and common species occuring both in artisanal catches and trawl bycatches were analysed for differences between fishery types and seasons using 2-way ANOVA or Kruskal-Wallis test depending on homoscedascity of the variances. The same test was also used for significant differences in finfish species diversity (species richness *S* and Shannon-Wiener diversity index *H'*) between fishery types and seasons.

5.4. Results

5.4.1. Finfish trawl bycatch distribution patterns, composition and abundance

Finfish trawl bycatch rates were on the average higher inshore than offshore (191.6 ± 42.9 kg/h and 26.2 ± 9.4 kg/h respectively, Table 1). Results of Kruskal-Wallis test indicated significant differences in bycatch rates between the inshore and offshore areas, and to a lesser extent significant between the seasons (Table 2). The finfish bottom total biomass over the study area of 546.4 nm^2 was lower at 4,673 t for the NEM survey, and substantially higher at

6,169 t for the SEM. Total biomass was on average lower offshore and higher inshore (Table 1). Kruskal-Wallis test indicated significant difference in biomass between the inshore and offshore areas and to a lesser extent between the seasons (Table 2).

Table 1. Finfish bycatch rates (mean ± SE) and biomass (kg/nm²) by trawled area (inshore and offshore) and by seasons (Northeast Monsoon, NEM and Southeast Monsoon, SEM) in the Malindi-Ungwana Bay, Kenya.

Area	Season	Bycatch rate kg/h	Biomass kg/nm²
Inshore	NEM	123.5 ± 54.5	8,565.9 ± 3,781.5
Inshore	SEM	106.5 ± 17.5	7,427.5 ± 1,221.6
Offshore	NEM	6.2 ± 1.9	631.3 ± 210.0
Offshore	SEM	56.9 ± 19.3	4,067.4 ± 1,306.7

Table 2. Results of Kruskal-Wallis non-parametric test showing significant differences in bycatch rates (kg/h) and biomass (kg/nm2) between trawled areas and between seasons, in Malindi-Ugwana Bay, Kenya.

Factors	Df	N	Bycatch rate (kg/h)		Biomass (kg/nm²)	
			Statistic	p-value	Statistic	p-value
Area	1	78	26.462	***< 0.001***	25.489	***< 0.001***
Season	1	78	4.147	***0.042***	4.046	***0.044***

Seven and ten of the most abundant fish families contributed 66.6% and 59.7% to the total biomass during the NEM and SEM surveys respectively (Table 3a&b). In the NEM survey, *Galeichthys feliceps* alone contributed 26.3% in depths of 0–40 m. In this survey, the families Leiognathidae and Mullidae, were the most speciose (7 and 8 species each) and contributed 3.1% and 2.7% respectively to the total biomass in depths of 0–100 m. Three species of sciaenids (*Otolithes ruber, Johnius amblycephalus* and *Johnius dussumieri*) contributed 2.9% in depths of 0–40 m. In the SEM survey, *Lobotes surinamensis* contributed with the highest biomass representing 12.8% in depths of 0-20 m. Similarly to the NEM survey, the Leiognathidae (8 species) and Mullidae (7 species) were the most speciose at 0–

100 m depth in the SEM survey. The haemulids (6 species) and sciaenids (3 species) contributed 6.7% and 2.8% each to the total biomass in depths of 0–40 m in this survey.

Table 3. Composition of bycatch fish taxa with the highest proportions of biomass in the Malindi-Ungwana Bay, Kenya during (a) Northest Monsoon (NEM) and (b) Southeast Monsoon (SEM) surveys.

a. Taxon: NEM survey	Common name	Contribution to total biomass (%)	Biomass (t)	Depth range (m)
ARIIDAE		26.3	1,228.60	0-40
Galeichthys feliceps	Sea catfish			
CLUPEIDAE/PRISTIGASTERIDAE		12.7	595.2	0-40
Pellona ditchela	Indian pellona			
Hilsa kelee	Kelee shad			
TRICHIURIDAE		9.4	441.1	0-40
Trichiurus lepturus	Cutlassfish			
LOBOTIDAE		9.3	434.3	0-20
Lobotes surinamensis	Tripletail			
LEIOGNATHIDAE		3.1	146.9	0-100
Equulites elongatus	Slender ponyfish			
Leiognathus lineolatus	Ornate ponyfish			
L. equulus	Common ponyfish			
Photopectoralis bindus	Orange-tipped ponyfish			
L. daura	Goldstrip ponyfish			
Leiognathus sp.	Ponyfish			
Secutor insidiator	Pugnose ponyfish			
SCIAENIDAE		2.9	137.8	0-40
Otolithes ruber	Snapper kob			
Johnius amblycephalus	Bellfish			
J. dussumieri	Small kob			
MULLIDAE		2.7	126.8	0-100
Upeneus taeniopterus	Finstrip goatfish			
U. sulphureus	Sulphur goatfish			
U. japonicus	Bensasi goatfish			
U. vittatus	Yellow banded goatfish			
U. moluccensis	Goldband goatfish			
U. barberinus	Dash-and-dot goatfish			
Mulloidichthys vanicolensis	Yellowfin goatfish			
Parupeneus macronemus	Long-barbel goatfish			

b. Taxon: SEM survey				
LOBOTIDAE		12.8	787.8	0-20
Lobotes surinamensis	Tripletail			
LEIOGNATHIDAE		8.7	534.2	0-100
Secutor insidiator	Pugnose ponyfish			
Leiognathus daura	Goldstrip ponyfish			
L. equulus	Common ponyfish			
L. equulus	Common ponyfish			
Photopectoralis bindus	Orange-tipped ponyfish			
Equulites elongatus	Slender ponyfish			
L. lineolatus	Ornate ponyfish			
L. fasciatus	Stripped ponyfish			
Gazza minuta	Toothed soapy			
ARIIDAE		7	429.5	0-40
Galeichthys feliceps	Sea catfish			
Galeichthys sp.	Sea catfish			
Arius africanus	African sea catfish			
HAEMULIDAE		6.7	410.2	0-40
Pomadasys maculatus	Saddle grunt			
P. multimaculatum	Cock grunter			
P. stridens	Striped piggy			
Plectorhinchus gaterinus	Blackspotted grunt			
P. pictus(Diagramma pictum)	Trout sweetlips			
P. schotaf	Minstrel sweetlips			
DASYATIDAE		6.1	376	0-20
Himantura gerrardi	Sharpnose stingray			
MULLIDAE		4.6	283.9	0-100
Upeneus sulphureus	Sulphur goatfish			
U. japonicus	Bensasi goatfish			
U. tragula	Freckled goatfish			
U. vittatus	Yellow banded goatfish			
U. taeniopterus	Finstrip goatfish			
Parupeneus macronemus	Long-barbel goatfish			
Mulloidichthys flavolineatus	Yellowstripe goatfish			
CLUPEIDAE/PRISTIGASTERIDAE		3.8	235.2	0-100
Pellona ditchela	Indian pellona			
Sardinella gibbosa	Goldstripe sardinella			

DIODONTIDAE		3.8	232.6	20-40
Diodon hystrix	Spot-fin porcupinefish			
CARCHARHINIDAE		3.6	222.9	0-40
Carcharhinus sealei	Blackspot shark			
C. melanopterus	Blacktip reef shark			
Carcharhinus sp.	Shark			
SCIAENIDAE		2.8	171.8	0-40
Otolithes ruber	Snapper kob			
Johnius amblycephalus	Bellfish			

The MDS plots for the two surveys combined showed a distinct separation of finfish bycatch species composition by area (Fig. 2a) and to a lesser extent by season (Fig 2b) (2-way ANOSIM: for area $R = 0.584$; $p = 0.001$, for season $R = 0.162$; $p = 0.001$). The inshore area A and inshore area B showed no difference but differed from A&B offshore as shown by pairwise comparisons. SIMPER results indicated that the spatial differences in composition was due to more abundant *Galeichthys feliceps* and *Pellona ditchela* in samples from the inshore area (Table 4), compared to more abundant *Trachinocephalus myops*, *Bothus mancus* and *Callionymus gardineri* offshore (Table 5). The seasonal difference was attributed to more abundant *B. mancus, G. feliceps, T. myops, C. gardineri* and *P. ditchela* during the NEM survey, and more abundant *Psettodes erumei* in the SEM (Table 6).

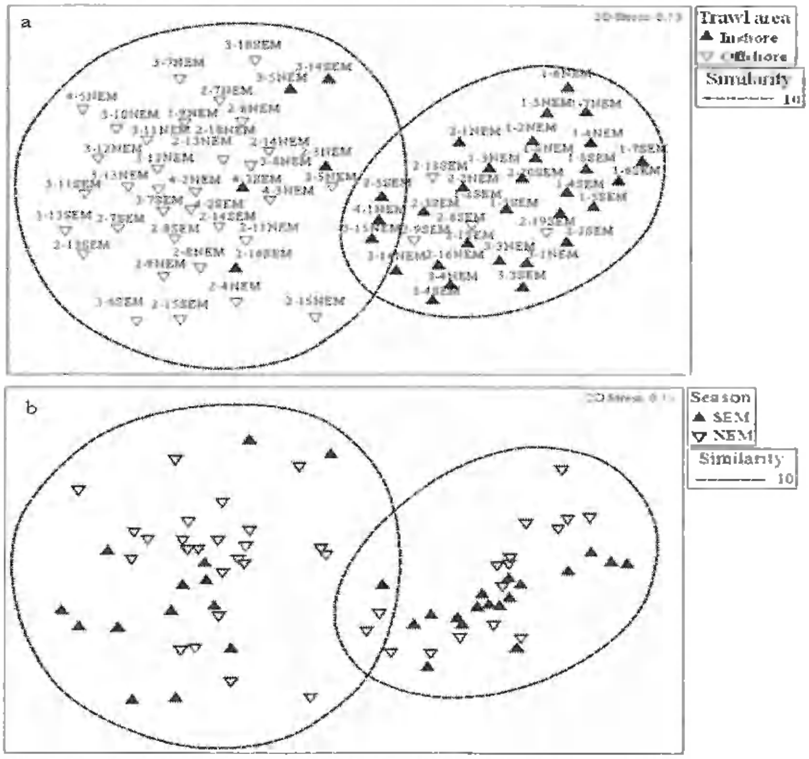

Figure 2. Non-metric MDS plots (with indication of similarity levels of 10) showing the composition of finfish bycatch by (a) area and by (b) season in Malindi-Ungwana Bay, Kenya based on species abundance for the combined Northeast Monsoon (NEM) and Southeast Monsoon (SEM) surveys.

Table 4. SIMPER: Species contributing most to the similarity in terms of abundance (%) between inshore trawl bycatches and artisanal catches with average similarities of 23.3% and 9.3% respectively in the Malindi-Ungwana Bay, Kenya.

Species	Average abundance	Average similarity	% contribution
Inshore trawl bycatches			
Galeichthys feliceps	14.65	5.27	22.59
Pellona ditchela	9.12	2.79	11.97
Johnius amblycephalus	6.68	1.95	8.35
Leiognathus equulus	3.54	1.3	5.57
Pomadasys maculatus	4.05	1.1	4.71
Otolithes ruber	2.36	0.84	3.61
Lobotes surinamensis	0.95	0.22	0.96
Artisanal catches			
Lobotes surinamensis	7.52	1.4	14.98
Galeichthys feliceps	5.2	0.8	8.61
Pellona ditchela	4.09	0.7	7.45
Otolithes ruber	3.9	0.58	6.23
Pomadasys maculatus	2.5	0.3	3.17
Leiognathus equulus	1.24	0.13	1.44
Johnius amblycephalus	1.15	0.12	1.33

Table 5. SIMPER: Species contributing most to the dissimilarity in terms of abundance (%) for offshore trawl bycatches versus artisanal catches showing the percentage contribution of bycatch fish species with an average dissimilarity of 99.0% in Malindi-Ungwana Bay, Kenya.

Species	Average abundance		Average dissimilarity	%contrib.
	Offshore trawl bycatches	Artisanal catches		
Bothus mancus	11.96	0.10	5.62	5.67
Trachinocephalus myops	11.91	0.00	5.49	5.54
Lobotes surinamensis	0.00	7.52	3.79	3.83
Lutjanus fulviflamma	0.02	5.85	3.05	3.08
Callionymus gardineri	7.34	0.00	2.96	2.99
Galeichthys feliceps	0.08	5.20	2.87	2.90
Psettodes erumei	0.06	6.41	2.86	2.89
Pellona ditchela	0.66	4.09	2.71	2.74
Peocilopseta natalensis	4.94	0.00	2.63	2.66
Otolithes ruber	0.29	3.90	2.31	2.33
Leiognathus lineolatus	5.18	0.03	2.25	2.27
Siganus sutor	0.16	3.70	1.88	1.90
Thryssa vitirostris	0.03	2.79	1.65	1.67
Lethrinus lentjan	0.41	2.51	1.57	1.58
Pomadasys maculatus	0.83	2.50	1.51	1.52
Upeneus bensasi	3.16	0.00	1.36	1.38
Upeneus taeniopterus	3.10	0.01	1.35	1.36
Aluteres monoceros	2.67	0.00	1.29	1.30
Carcharhinus melanopterus	0.01	2.69	1.23	1.24
Pseudanthias cooperi	2.41	0.00	1.20	1.22
Gerres oyena	0.53	1.87	1.16	1.17
Photopectoralis bindus	1.79	0.37	1.14	1.15
Mypristis pavo	1.91	0.00	1.08	1.10
Lethrinus harak	0.01	1.88	1.06	1.07
Secutor insidiator	1.73	0.04	1.06	1.07
Acanthurus xanthopterus	0.00	1.81	1.04	1.05
Scolopsis bimaculatus	1.51	0.00	0.99	1.00
Scomberoides commersonnianus	0.00	2.04	0.97	0.98

Table 6. SIMPER: Species contributing most to the dissimilarity in terms of abundance (%) for finfish catches in Southeast Monsoon (SEM) versus catches in Northeast Monsoon (NEM) season showing the percentage contribution of species with an average dissimilarity of 90.6% in Malindi-Ungwana Bay, Kenya.

Species	Average abundance		Average dissimilarity	%contrib.
	SEM season	NEM season		
Galeichthys feliceps	2.96	9.36	5.03	5.56
Lobotes surinamensis	4.75	3.51	4.47	4.93
Pellona ditchela	2.80	6.03	4.28	4.72
Lutjanus fulviflamma	2.91	3.41	3.73	4.12
Psettodes erumei	6.36	0.09	3.60	3.97
Otolithes ruber	1.98	3.42	3.25	3.59
Thryssa vitirostris	0.30	3.12	2.57	2.84
Siganus sutor	2.51	1.39	2.22	2.45
Lethrinus lentjan	1.19	1.72	1.98	2.19
Pomadasys maculatus	3.27	1.37	1.93	2.13
Johnius amblycephalus	1.29	3.04	1.69	1.87
Acanthurus xanthopterus	0.30	1.74	1.60	1.76
Lethrinus harak	0.43	1.67	1.57	1.74
Bothus mancus	1.96	5.03	1.56	1.72
Carcharhinus melanopterus	2.47	0.22	1.50	1.66
Leptoscarus vaigeinsis	0.29	1.55	1.38	1.52
Trachinocephalus myops	1.96	4.83	1.31	1.45
Gerres oyena	1.60	0.94	1.28	1.41
Scomberoides commersonnianus	1.57	0.49	1.22	1.35
Leiognathus equulus	1.72	1.31	1.08	1.19
Photopectoralis bindus	1.54	1.86	1.04	1.14
Callionymus gardineri	0.27	3.82	1.03	1.14
Terapon jarbua	0.81	0.76	1.01	1.11
Leiognathus lineolatus	0.56	3.22	0.99	1.09
Hilsa kelee	1.54	0.13	0.96	1.06
Caranx ignobilis	1.43	0.41	0.95	1.04
Upeneus taeniopterus	0.89	2.86	0.94	1.04
Secutor insidiator	1.41	2.61	0.93	1.03
Dentex marocannus	1.61	0.00	0.91	1.01

5.4.2. Species diversity of finfish trawl bycatches

A total of 11,914 fishes weighing 425 kg were sampled during the NEM survey, comprising 158 species in 61 families. During the SEM survey, 4,890 fishes weighing 569 kg were sampled, comprising 161 species in 57 families. Both the average species richness (S) and Shannon-wiener diversity index (H') per tow were higher during the SEM season than during the NEM, with the highest mean species richness of 19.8 recorded offshore during the SEM season (Table 7). Results of 2-way ANOVA indicated no significant difference in species richness between seasons, between areas, nor a significant effect due to the interaction of season with area (Table 8). The same test indicated a significant difference in Shannon-Wiener diversity index between the seasons but not between areas, nor was there a significant effect due to the interaction of season with area (Table 8).

Table 7. Seasonal mean (± SE) of finfish trawl bycatch species richness and Shannon-wiener diversity index by area and season in the Malindi-Ungwana Bay, Kenya.

Area	Season	Species richness (S)	Shannon-Wiener
Inshore	NEM	17.1 ± 1.5	14.9 ± 1.5
Inshore	SEM	18.4 ± 1.9	19.8 ± 2.8
Offshore	NEM	1.8 ± 0.1	1.8 ± 0.1
Offshore	SEM	2.3 ± 0.2	2.3 ± 0.2

Table 8. Results of 2-way ANOVA showing no significant difference in bycatch species richness between trawled areas and between seasons, and a significant difference in Shannon-Wiener diversity index between the seasons in Malindi-Ungwana Bay, Kenya (p-value bold and italic is significant).

Factors	Df	Error Df	Species richness (S)		Shannon-Wiener diversity index (H')	
			F	p-value	F	p-value
Area	1	69	0.511	0.477	0.131	0.719
Season	1	69	2.654	0.108	14.951	***0.0003***
Area × Season	1	69	0.308	0.581	0.579	0.449

5.4.3. Comparison of finfish artisanal catches and trawl bycatches: species composition and sizes

Comparison of species diversity was done between the 2 fishery types: trawl fishery (inshore and offshore bycatches) and artisanal fishery (artisanal catches). The trawl bycatches (with 158 and 161 species during the NEM and SEM seasons respectively), contained an overall number of 223 species, while in the artisanal catches, a total of 90 and 148 species were recorded in the NEM and SEM season respectively, with an overall number of 178 species. Species richness (S) for artisanal catches was higher during NEM season (on average 12 per sample) and lower during SEM season (on average 9 per sample), while for the trawl, species richness of inshore bycatches was higher in SEM (on average 18 per tow) and lower in NEM (on average 17 per tow, Fig. 3a); for the offshore bycatches, species richness was also higher in SEM than NEM (on average 20 and 15 per tow respectively). The Shannon-Wiener diversity index (H') for the artisanal catches was slightly higher in NEM (on average 1.7 per sample) than in SEM (on average 1.6 per sample), while for both the inshore and offshore bycatches, it was higher in SEM (on average 2.3 per tow each) and lower in NEM (on average 1.7 and 1.8 per tow respectively Fig. 3b).

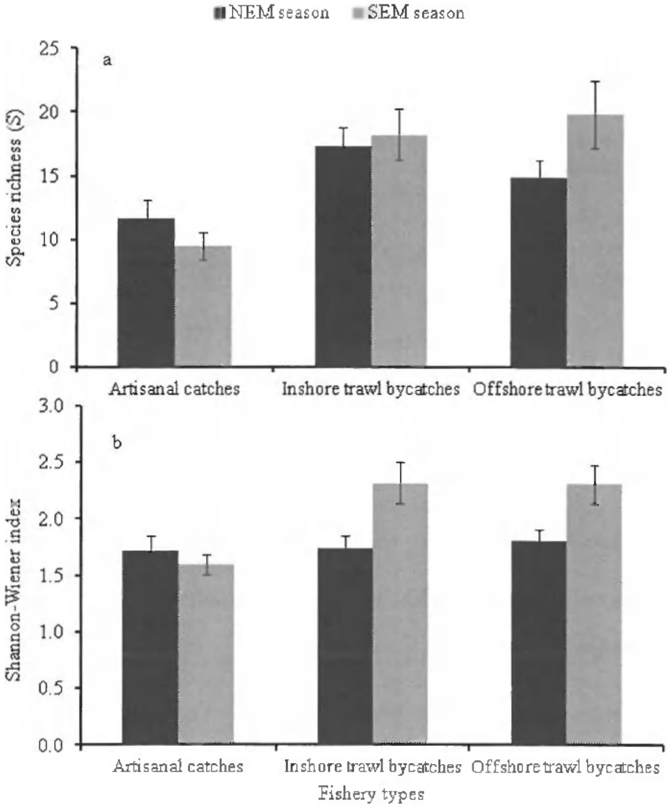

Figure 3. Comparison of mean (± SE) species richness (a) and Shannon-Wiener diversity index (b) per sample between artisanal catches and trawl bycatches during the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons in Malindi-Ungwana Bay, Kenya.

Results of 2-way ANOVA indicated a significant difference in species richness between the fishery types ($p < 0.05$) but not between seasons, nor was there a significant effect due to the interaction of fishery type with season ($p > 0.05$, Table 9). Post hoc pair-wise comparison showed significantly higher species richness for the trawl bycatches in both seasons ($p < 0.05$). The same test showed significant differences in Shannon-Wiener diversity index between the fishery types, seasons and a significant effect due to the interaction of fishery type with season ($p < 0.05$, Table 9). Post hoc pair-wise comparison indicated significantly higher Shannon-Wiener diversity index for the inshore and offshore trawl bycatches during both seasons ($p < 0.05$).

Table 9. Results of 2-way ANOVA showing significant differences in finfish species richness between fishery types (trawl bycatches and artisanal catches) and significant differences in Shannon-Wiener diversity index between fishery types, seasons and the interaction of fishery type with season in the Malindi-Ungwana Bay, Kenya (p-value bold and italic are significant).

Factors	Df	Error Df	Species richness (S)		Shannon-Wiener diversity index (H')	
			F	p-value	F	p-value
Area	2	149	14.718	***<0.001***	6.794	***0.002***
Season	1	149	0.834	0.363	8.178	***0.005***
Area × Season	3	149	2.726	0.069	5.089	***0.007***

The non-metric MDS plots (Fig. 4a) showed a distinct species composition between the artisanal catches and trawl bycatches, and to some extent between the seasons (Fig. 4b). Results of 2-way ANOSIM indicated a significant difference between the fishery types, and to a lesser extent between the seasons ($R = 0.317$; $p = 0.001$ and $R = 0.088$; $p = 0.003$ respectively). Pair-wise comparison tests showed the inshore trawl bycatches differed significantly from the offshore trawl bycatches ($R = 0.631$; $p = 0.001$), but not from the artisanal catches ($R = 0.066$; $p = 0.090$). Also the offshore trawl bycatches significantly differed from the artisanal catches ($R = 0.460$; $p = 0.001$). The differences in composition between offshore trawl bycatches and artisanal catches was due to more abundant *Bothus mancus*, *Trachinocephalus myops*, *Callionymus gardineri* and *leiognathus lineolatus* in offshore trawl bycatches (Table 5), and more abundant *L. surinamensis*, *L. fulviflamma*, *G. feliceps*, *P. erumei* and *P. ditchela* in artisanal catches (Table 5). While seasonal differences in composition between the fishery types was due to more abundant *G. feliceps*, *P. ditchela*, *Bothus mancus*, *Thryssa vitrirostris* and *T. myops* in NEM, and more abundant *P. erumei* in the SEM season (Table 6).

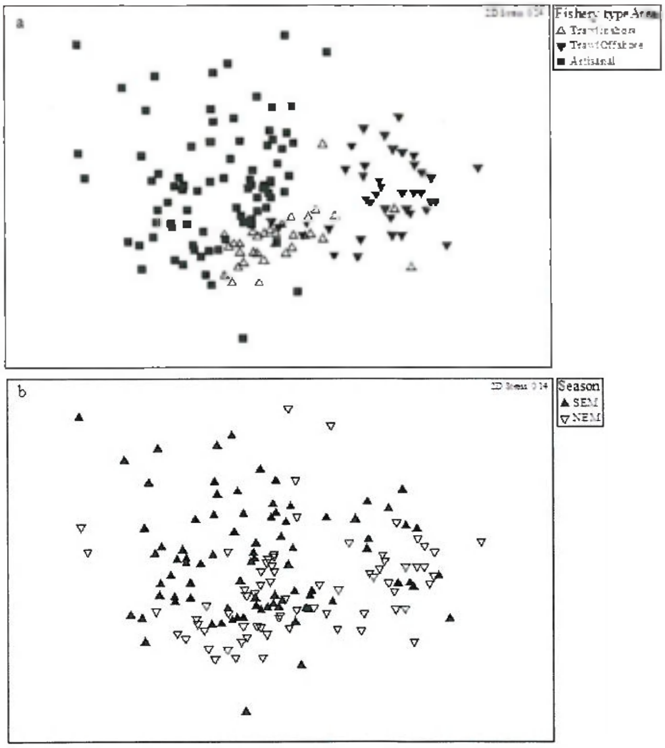

Figure 4. Non-metric MDS plots showing the composition of finfish catches by (a) fishery type and by (b) season in Malindi-Ungwana Bay, Kenya based on fish species abundance for the combined trawl bycatches and artisanal catches during the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons.

Results of 2-way SIMPER for inshore trawl bycatches *versus* artisanal catches with average similarities of 23.3% and 9.3% respectively indicated a total of 7 common species explaining the similarity (Table 4). The relative abundance of individual species was higher both in inshore trawl bycatches and artisanal catches compared to those in offshore trawl bycatches (Fig. 5). The 14 most abundant species from artisanal catches, inshore trawl bycatches and offshore trawl bycatches (Fig. 6) indicated at least 6 of the 7 species explaining the similarity occured in both the artisanal catches and inshore trawl bycatches. Size comparison of these 7 most abundant and common for both artisanal catches and trawl bycatches showed that except for *Lobotes surinamensis* all the species were significantly smaller in size for the trawl bycatches ($p < 0.05$), while seasonal differences in sizes were only significant for *Lobotes surinamensis* and *Leiognathus equulus* ($p > 0.05$, Table 10).

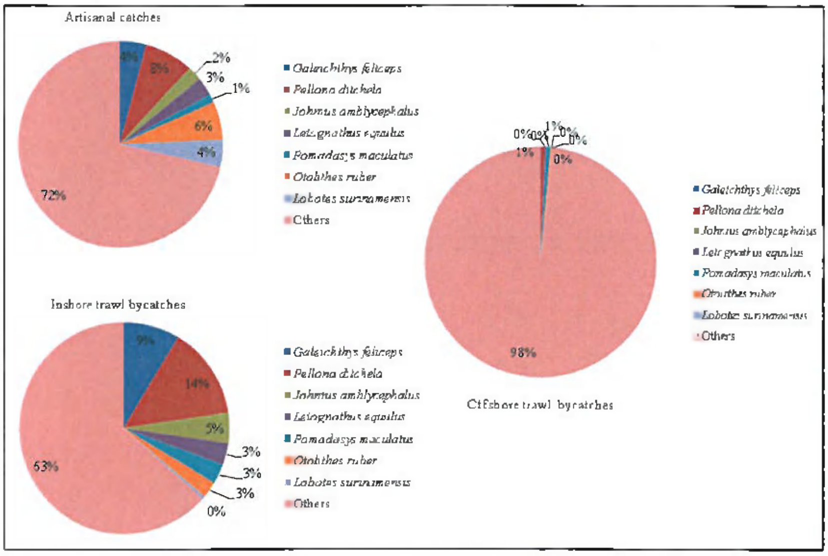

Figure 5. Similarity in finfish species occuring in artisanal catches and inshore trawl bycatches showing higher relative abundance both in artisanal and inshore trawl than in offshore trawl bycatches in the Malindi-Ungwana Bay, Kenya.

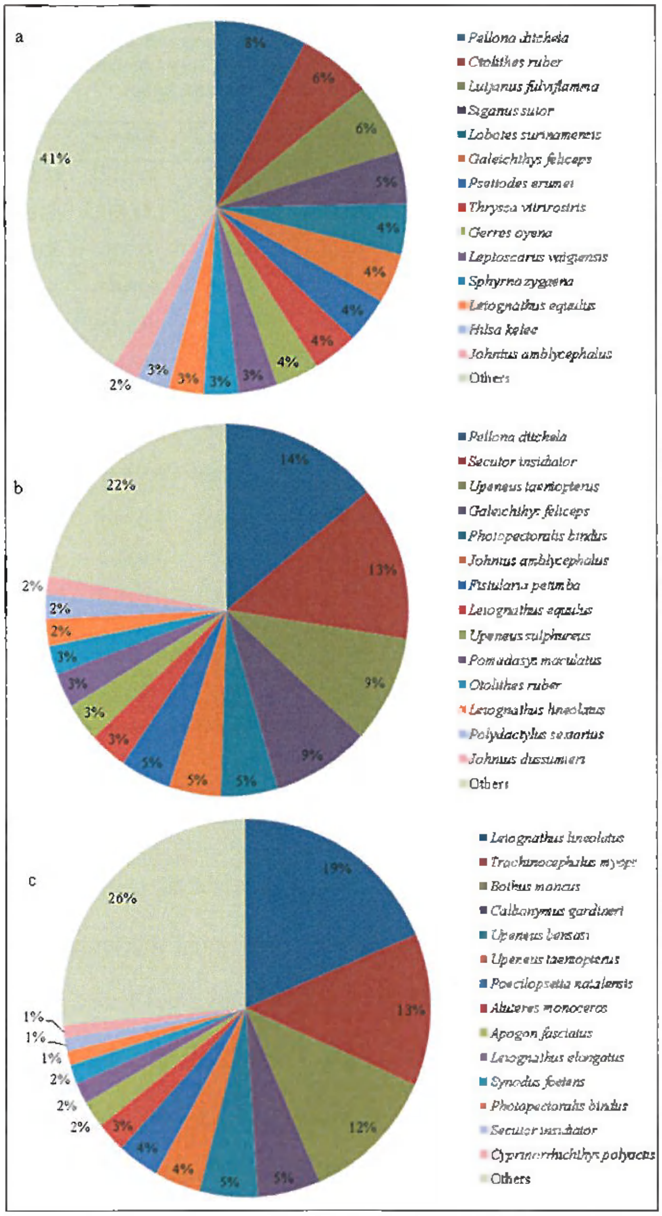

Figure 6. The most abundant 14 finfish species from catches of (a) artisanal (b) inshore trawl and (d) offshore trawl in the Malindi-Ungwana Bay, Kenya, showing common and most abundant species between (a) artisanal catches and (b) inshore bycatches.

Table 10. Mean total lengths (cm± SE) of the most abundant and artisanal target fish species which occurred in artisanal catches and trawl bycatches during the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons in Malindi-Ungwana Bay, Kenya with trawl bycatches indicating significantly smaller individuals than those in artisanal catches ($p < 0.05$, bold and italic).

Species	Artisanal	Trawl	N/Error Df	Statistic	p-value	Test
Galeichthys feliceps	39.8 ± 1.3	20.5 ± 0.3	357	227.171	***<0.001***	Kruskal-Wallis
Johnius amblycephalus	14.4 ± 1.8	11.4 ± 2.2	228	51.819	***<0.001***	2-way ANOVA
Pellona ditchela	14.8 ± 0.4	13.6 ± 0.1	787	8.272	***0.004***	2-way ANOVA
Lobotes surinamensis	56.2 ± 0.9	55.1 ± 1.7	298	3.045	0.082	2-way ANOVA
Otolithes ruber	24.3 ± 0.3	18.9 ± 0.2	380	165.400	***<0.001***	Kruskal-Wallis
Leiognathus equulus	12.5 ± 0.2	13.3 ± 0.1	448	19.218	***<0.001***	Kruskal-Wallis
Pomadasys maculatus	21.9 ± 0.6	12.9 ± 0.1	289	299.596	***<0.001***	Kruskal-Wallis
	NEM season	SEM season				
Galeichthys feliceps	25.8 ± 0.7	24.4 ± 0.7	357	0.129	0.719	Kruskal-Wallis
Johnius amblycephalus	11.9 ± 2.5	11.8 ± 2.2	228	0.960	0.328	2-way ANOVA
Pellona ditchela	14.4 ± 0.4	14.0 ± 0.1	787	0.002	0.968	2-way ANOVA
Lobotes surinamensis	59.4 ± 1.3	53.2 ± 1.0	298	12.823	***<0.001***	2-way ANOVA
Otolithes ruber	21.4 ± 0.3	20.9 ± 0.3	380	1.093	0.296	Kruskal-Wallis
Leiognathus equulus	13.4 ± 0.2	12.7 ± 0.1	448	13.349	***<0.001***	Kruskal-Wallis
Pomadasys maculatus	17.1 ± 0.4	16.6 ± 0.5	289	2.857	0.910	Kruskal-Wallis

5.5. Discussion

Despite high species richness of bycatches produced in the tropical shrimp trawl fisheries, fish bycatches are typically dominated by only a few species and families (Fennessy, 1994), as also found in the Malindi-Ungwana Bay bottom trawl surveys. In this study, the number of dominant fish families also varied with season, with slightly higher number of families and or species associated with the wet Southeast Monsoon (SEM) season. Where similar bottom trawl surveys were conducted, this present study compare well with bycatches on the Tugela Bank off eastern South Africa where a dominance of six different species of finfish contributed for 80% to the total biomass (Fennessy, 1994), and the northwestern Australian prawn trawl fishery where a dominant of six finfish families contributed for 81.6% to the total biomass (Tonks et al., 2008).

The present study indicated that trawl bycatch rates and biomass decreased from inshore to offshore. This pattern reflected the depth distribution by individual fish families, and depended to some extent on season. Whereas some families were restricted to 0–20 m depth (Lobotidae, Dasyatidae), others occurred over a broader depth range of 0–40 m (Ariidae, Trichiuridae, Sciaenidae, Haemulidae) or 0–100 m (Leiognathidae, Mullidae). The biomass of Clupeidae occurred over a narrower depth range during the NEM survey (0–40 m) but a broader distribution of this family during the SEM season was recorded, signifying the distribution of this species is dependent on season. Similarly to the present results, Fennessy (1994) showed depth preference of six species of elasmobranchs caught as bycatch by trawlers on the Tugela Bank, and similarly, bycatches of flatfishes (Paralichthyidae) were distributed over a broader depth range than the Pleuronectidae in the Gulf of California (Rabago-Quiroz et al., 2008). The bycatch of *Galeichthys feliceps*, *Pellona ditchela*, *Johnius amblycephalus*, *Leiognathus equulus*, *Pomadasys maculatus*, *Lobotes surinamensis* and *Otolithes ruber* were more abundant in the inshore area (Tana and Sabaki estuaries), where they also form a target catch of the artisanal fishery. Conversely *Trachinocephalus myops* and *Bothus mancus*, less targeted in the artisanal fishery, were more abundant in offshore waters of the bay.

Given the gradients of trawl bycatches occurring across area and season in the Malindi-Ungwana Bay, the need for a framework for marine spatial planning in addition to the already existing measures of bycatch reduction may be required (Douvere, 2008; Groeneveld et al., 2012). This will help further in the reduction of resource use conflicts between the shrimp bottom trawl and artisanal fishery. Species distribution in the bay was also species-specific. For example, *Lobotes surinamensis* targeted in artisanal fishery had the narrowest depth range distribution in the bay (0–20 m, Table 3). Therefore, this species has a lower escape chance and is possibly more vulnerable to over-exploitation and resource use conflict between the artisanal fishery and shrimp bottom trawl, than widely distributing species with higher escape chances. To protect both the narrow and wide distributing species from trawling impact as bycatch, appropriate measures will be required. The stipulated measure on closed season for shrimp trawling (beginning of November to end of March every year) in the Malindi-Ungwana Bay shrimp fishery management plan is therefore appropriate. The closed season falls partly within the dry Northeast Monsoon (NEM) season which is important for the recovery of both shrimps, and particularly fish species that occur as trawl bycatches. The proposed creation of closed areas by the management plan in the bay however, may not be the best management option since it does not take into account the distribution ability of fish species (Table 3a&b), and this can only work best for the less vagile species.

Apart from landing high species diversity of finfish bycatch, tropical shrimp trawl fisheries are also associated with large volumes of bycatch that consist mostly of undersize and immature individuals. The Malindi-Ungwana Bay study was no exception. Six of the seven most abundant artisanal target species that also occurred in inshore trawl bycatch had significantly smaller sized individuals (Table 10). With continued and intensive trawling especially in the inshore area, such affected fish species which are otherwise a target in the artisanal fishery, are possibly given less time to recruit before capture or may be totally depleted. This scenario may explain possibly why the Malindi-Ungwana Bay artisanal fishery after a long period of trawling activity before the trawl ban in 2006, had started experiencing reduced artisanal catches (Munga et al., 2012a), and this needs to be considered for further management. In addition, the small sized individuals of a majority of trawl bycatches especially in offshore, were composed of low commercial value species, such as *Bothus mancus, Callionymus gardineri, Aluteres monoceros* and *Apogon fasciatus* (Fig. 6), which confirms findings by Rabago-Quiroz et al., (2008). These authors reported the majority of trawl bycatch fish species sampled in a survey off the Gulf of California to be mostly small sized individuals ranging between 6–18 cm in total length. Since tropical shrimp trawl bycatch species richness is high, coupled with many small and juvenile individuals, there is a high risk of reduced species diversity and to some extent disappearance of certain species, as observed by Chong et al., (1987) when assessing the effects of a 1978 sustained ban on trawling in an Indonesian shrimp fishery. So far in Malindi-Ungwana Bay, no single study has established a complete disappearance of some species due to the impact of trawling, but reduced catches in the artisanal fishery before the ban in 2006 have been confirmed to some extent (Munga et al., 2012a). In order to avoid this risk of biodiversity loss, emphasis on the use of effective Bycatch Reduction Devices (BRDs) that allow escape of small sized and juveniles should be made mandatory in the Malindi-Ungwana Bay.

This study concludes that the inshore area of the Malindi-Ungwana Bay which is also accessible to the artisanal fishermen, is richer in fish abundance and diversity than the offshore area. The most abundant and affected finfish species which are also a target by the artisanal fishery were *Galeichthys feliceps, Pellona ditchela, Johnius amblycephalus, Leiognathus equulus, Pomadasys maculatus, Lobotes surinamensis* and *Otolithes ruber*. Coincidentally this inshore area harbours abundant shrimps (Munga et al., 2013) for commercial trawling and artisanal harvesting as well, thereby confirming the existing potential of resource-use conflict. Therefore, in order to avoid this conflict in the bay, the stipulated measures in the management plan of minimum trawling distance of $\geq$ 3 nm offshore, closed trawling season, and the mandatory use of BRDs should be emphasised, in addition to continued prohibition of night trawling in order to achieve sustainable utilisation of fisheries resources in the bay. Continued monitoring of finfish trawl bycatch quantities and species diversity is however, recommended in the bay so as to get a clearer spatio-temporal pattern for effective management measures.

Acknowledgements

This study was part of the South West Indian Ocean Fisheries Project (SWIOFP) under Component 2 (shallow water trawl surveys). The first author (CNM) was financially supported by the VLIR ICP PhD program in association with the Gent University, Belgium. The KMFRI technical team, fellow researchers, captain and crew of the wet-leased trawler FV Vega are thanked for their many contributions during field work and data analyses, and Teresa Athayde is thanked for logistic support during the planning of the surveys. The Director of KMFRI and Ministry of Fisheries Development in Kenya are thanked for granting a special research licence for the surveys.

Photo credit: C.N. Munga, 2013 at Mijikenda fishing camp, right and Ras-Ngomeni fish landing site, left in Malindi-Ungwana Bay, Kenya.

Chapter 6

6. Contribution of artisanal fishing to fishers' livelihoods and their perceptions of shrimp trawling in Malindi-Ungwana Bay, Kenya

Cosmas N. Munga[1,2*], Victor Mwakha[1], Jacob Ochiewo[1], Edward Kimani[1] and Ann Vanreusel[2]

[1]Kenya Marine and Fisheries Research Institute, P.O. Box 81651 – 80100, Mombasa, Kenya.

[2]Gent University, Marine Biology Reseach Group, Krijgslaan 281-S8, 9000, Gent, Belgium.

6.1. Abstract

The Malindi-Ungwana Bay in Kenya is important for its artisanal fisheries as well as semi-industrial shrimp trawling. A survey was conducted to assess the contribution of different categories of artisanal fishing and the importance of fishing to fishers' livelihoods, and to evaluate how artisanal fishers perceived shrimp trawling in the bay. The Net Present Value (NPV) was used to evaluate the economic viability of the different fishing categories, while fishers' perceptions of shrimp trawling was assessed using questionnaires in semi-structured interviews. Results indicated that livelihood diversification was practiced by a majority of fishers in the bay. Full time fishers were associated with higher average daily fish catches and incomes from fish sales compared to catches and incomes from fishers who undertook additional livelihoods. However, economic viability of artisanal fishing was improved when additional livelihood sources of fish trading and micro-business, part time paid-up jobs, and use of acquired skills for making extra income were undertaken. This was contrary to when artisanal fishing was undertaken with subsistence farming or when full time fishing was undertaken alone. Majority of artisanal fishers from all fishing categories except those who engaged in part time paid-up jobs perceived a negative impact of shrimp trawling mostly due to its associated damage to artisanal fishing gear, fish habitat, and excessive bycatches that are otherwise targeted by the artisanal fishers.

Key words: Artisanal fishing; Livelihood diversification, Net Present Value; Trawling perceptions; Malindi-Ungwana Bay; Kenya.

6.2. Introduction

The coastal artisanal or small-scale fisheries throughout the tropics play an important socio-economic role for artisanal fishers and the coastal population at large (Kronen, 2004). Fish and other marine organisms, are the only renewable resources providing artisanal fishers with a primary source of income and economic security. Lack of alternative livelihoods have resulted to high poverty levels among coastal fishing communities and unprecedented pressure on the fisheries resources (Davies et al., 2009; Kronen et al., 2010). In Fiji for example, fish consumption ranges between 187 g/person.day in urban areas to 260 – 270 g/person.day, and 280 – 470 g/person.day at smaller outer islands (Kuster et al., 2006; Turner et al., 2007), which is very high compared to the required 3,700 g/person/year as a minimum fish protein supply (Bell et al., 2009). The extent to which these communities are dependent on coastal resources is determined by the availability of other resources such as arable land and alternative income sources (Allison and Ellis, 2001). To achieve sustainable utilisation of the artisanal fisheries, management should shift from the long-established goals of improving technology, fishery efficiency and productivity, to embracing a wider rural development approach that accomodates developement of alternative income opportunities (Kronen et al., 2012). However, before a proper development plan for these coastal communities can be put in place, a full characterisation of the artisanal fisheries has to be done.

The artisanal fishery is best characterised by its manual-operation, multigear, multifleet and multispecies nature, with many managerial challenges that are associated with its open-access (McClanahan and Mangi, 2004). More so, this fishery is characterised by little enterpreneural skills, small informal groups, small traditional fishing vessels or no vessels, low capital investment, and correspondingly low productivity (Kronen, 2004), and occasionally the use of illegal fishing methods. In addition, this fishery has been affected by detrimental impacts of development and lifestyle changes, exacerbated by weather and seasonal changes, increased habitat degradation, pollution, and subsequent declined catches (Friedlander and DeMartini, 2002; Cinner et al., 2009). With this threat of declining fishery resources, several government policies and fisheries projects have been designed and implemented in order to improve the coastal artisanal fisheries with a view to increase production, proper handling and storage of fish, and sustainable resource use. Despite being a common economic activity for most communities of the developing coastal and island states in the tropics, fishing is considered of low importance compared to other occupations and is only pursued by most households due to its immediate financial gains compared to the time-consuming farming activity (Turner et al., 2007).

The Malindi-Ungwana Bay in Kenya, not only supports over 3,500 artisanal fishers with an annual fish landing of between 885.4 – 1,540 t, it also has the only semi-industrial shrimp trawl fishery in Kenya (Munga et al., 2012a). The artisanal fishers in the bay target finfish, molluscs (squids and octopus), and crustaceans (shrimps, crabs and lobsters), while the semi-industrial trawl fishery targets the penaeid shrimps but also produces large bycatches of finfish (Mwatha, 2005; Munga et al., 2012a). For the first time, this present study has assessed the local dependency on the artisanal fishery in the bay by using the Net Present Value (NPV) analysis to evaluate the economic viability of the different artisanal fishing enterprises. Economic viability is how an activity or enterprise can support itself financially. Dependency surveys are relevant in order to identify the need and importance for diversification of incomes. In addition, the artisanal fishers' perceptions of the impact of shrimp trawling was assessed for the area, in order to identify the acceptance of shrimp trawling. Therefore, two hypotheses were tested: 1) full time artisanal fishers have higher daily catches and income and therefore, higher NPV than other artisanal fishers who are also engaged in alternative livelihood sources, and 2) perceptions of shrimp trawling by artisanal fishers differed between artisanal fishing categories, education levels and fishing areas.

6.3. Materials and methods

6.3.1. Data collection

The use of questionnaires in semi-structured interviews was conducted in March 2013 (towards end of the peak fishing season for coastal fisheries in Kenya). Semi-structured interview is a method of research in social science which is open, allowing new ideas to be brought up during the interview process as a result of what the respondent says. These interviews were conducted in different artisanal fishing camps along the Malindi-Ungwana Bay in three main areas: at the Malindi area (Mijikenda camp), Ngomeni area (Ras Ngomeni and Kinyaole camps), and Kipini area (Shekiko camps) (Fig. 1). The camps are temporary settlements for the artisanal fishers, sometimes living there with their families. These camps are located near fish landing sites, where fishers conduct their daily activities (Fig. 2). Depending on fishing season, fishers temporarily migrate locally between fishing camps along the bay in search of better catches or safer and sheltered fishing grounds. The questionnaire (see appendix) was administered in Kiswahili, the national language and spoken by all the respondents. In these fishing camps, with the help of the camps chairmen, willing fishers were interviewed at an individual level, after they returned from fishing. Fishers were interviewed about their fishing practices, catches and incomes, level of education, household characteristics, and their perceptions of the impact of shrimp trawling in the area. Only fishers were interviewed as representative heads of their households.

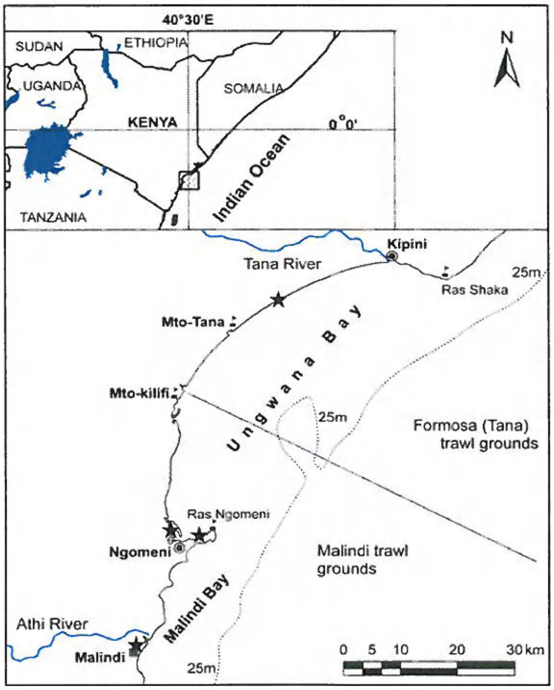

Figure 1. Map of the East African coast showing location of the Malindi-Ungwana Bay, Kenya with black star marks indicating sites where fishers were randomly interviewed in their camps at Malindi, Ngomeni and Kipini fishing areas (adapted from Munga et al., 2012a).

Figure 2. Two of the fishing camps that were visited during the study (a) Mijikenda at Malindi area showing shrimp catches ready for sell to a buyer, and (b) Kinyaole at Ngomeni fishing area (Photo credit: C.N. Munga, 2013)

6.3.2. Data analyses

Artisanal fishing activity was classified into five categories (Table 1): full time fishing for artisanal fishers without any other alternative livelihood sources, artisanal fishers who also engaged in part time paid-up jobs, artisanal fishers who were also trading in fish and other micro-businesses, fishers who also practised subsistence farming, and fishers who made extra income using acquired skills.

Table 1. Categories of artisanal fishing, main characteristics, fishing gear and vessels in the Malindi-Ungwana Bay, Kenya.

Fishing category	Main characteristics	Main fishing gear	Main fishing craft/vessels
Full time fishing	No alternative livelihood sources.	Castnets, gillnets, monofilament nets, handlines, longlines, prawn seines, scoop nets.	Canoes, fibreglass boats, outriggers, *mashua*, use of foot
Fishing with part time paid-up jobs	Casual jobs: loading, boat cleaning, light transport service, painting, cleaning service, salt works.	Gillnets, handlines, monofilament nets, longlines, prawn seines.	Canoes, *mashua*, fibreglass boats, use of foot.
Fishing with fish trading and micro-businesses	Buying and selling of fish, small-scale businesses: mini shops and green grocers, camping service.	Castnets, gillnets, monofilament nets, handlines, longlines, prawn seines.	Canoes, fibreglass boats, *mashua*, use of foot.
Fishing with subsistence farming	Crop farming, poultry keeping.	Castnets, Gillnets, prawn seines, handlines, monofilament nets.	Canoes, *mashua*, use of foot.
Fishing with acquired skills for extra income	Carpentry, key cutting, boat building and repair, driving, basketry, wine tapping.	Castnets, gillnets, handlines, longlines, monofilament nets, prawn seines, skin diving.	Canoes, *mashua*, surf boards, fibreglass boats, use of foot.

Two-way Analysis of Variance (ANOVA), a parametric test was used to test for significant differences in fishers' age, household size, and daily income between fishing categories, areas and their interaction. The ANOVA test, when significant was followed by Tukey HSD post hoc pair-wise comparison test, and Levene's test was used to confirm homoscedacity of the variances. Kruskal-Wallis non-parametric test was used for significant differences in average daily catches between fishing categories and between areas. Both the parametric and non-parametric tests were performed using STATISTICA v7.

The Net Present Value (NPV) was used to assess and compare the economic viability of the different identified artisanal fishing categories. This economic procedure calculates the present net value of an investment, in this case fishing category, using a discount interest rate, and series of future costs and incomes (revenue) over a given period (Kronen, 2004). The rate of discount is the rate charged by a central bank on loans to its member banks. All calculations were based on the following formula:

$$NPV = \sum_{i-1}^{n} \frac{Value^{i}}{(1+rate)^{i}} - Investment$$

where n is the number of cash flows in the list of values and rate, the rate of discount (in this case 18% for Central Bank Rate during the study time, March 2013) over the length period of 10 years. The local market prices of artisanal catches/landings (income) in Kenya Shillings (KES) by fishing category, the costs or expenses of all fishing gear and vessels, and annual expenses for their maintenance obtained from licensed shops within the study area were expressed in US Dollars (Table 2; 1 USD = 80.6 KES by March 2013).

Artisanal fishers' perceptions of shrimp trawling whether it had no impact or it had a negative impact such as damage to artisanal fishing gear and to fish habitat, reduced artisanal catches, crew job hire discrimination for locals by trawlers, accidents at sea while trawling, and flooding of local fish market by trawler fish bycatches were analysed by cross-tabulation in SPSS v16. Significant differences in shrimp trawling perceptions between fishing categories, fishers' education levels, and fishers' areas of operation were analysed using Chi-square test for independence (Pallant, 2001).

Table 2. Annual income and investment on fishing gear and vessels and expenses on repair by fishing category in the Malindi-Ungwana Bay, Kenya. The income was calculated from daily mean catch sales, gear and vessel costs from shops, and repair costs from fishermen.

Fishing category	Income (USD/year)	Gear costs	Vessel costs	Net repair (USD/year)	Vessel repair (USD/year	Total expenses (USD/year)
Full time fishing	3356.6	139.4	6519.9	774.2	86.6	7520.0
Fishing with fish trading & microbusiness	4438.2	412.3	5775.4	1032.2	65.0	7284.9
Fishing with acquired skills	3595.8	195.2	6085.6	1032.2	65.0	7378.0
Fishing with subsistence farming	2778.0	172.5	3914.4	1032.3	43.3	5162.5
Fishing with part time paid-up jobs	4144.4	356.5	5775.4	774.2	65.0	6971.1

6.4. Results

6.4.1. Composition of the artisanal fishers

A total of 151 artisanal fishers aged between 18 and 76 years were interviewed. Most fishers were interviewed in Ngomeni (48%; n = 73), followed by Malindi (37; n = 56) and Kipini (15; n = 22). Majority of fishers (42%; n = 64) were in full time fishing and most of them came from Ngomeni (59%; n = 38). Fishers in part time paid-up jobs were second most numerous (18%; n = 27) with the majority of these coming from Ngomeni as well (37%; n = 10). Fishers with acquired skills (12%; n = 18) such as net mending, boat building and repair among others were also most frequently interviewed at Ngomeni (61%; n = 11), while those engaged in fish trading and micro-business (17%; n = 25) came mainly from Malindi and Ngomeni too (Fig. 3). However, all fishers with alternative livelihoods combined were more (58%; n = 87) than those without alternative livelihoods. In Kipini, majority (59%, n = 13) of fishers were local migrants, and 41% (n = 9) were locals. Local migrant fishers were the majority (54%, n = 30) in Malindi, followed by locals (39%, n = 22) and foreign migrant fishers from the neighbouring Tanzania with a composition of 7% (n = 4). In Ngomeni, local migrant fishers made up the higher composition than the local fishers (68%, n = 50 and 32%, n = 23 respectively).

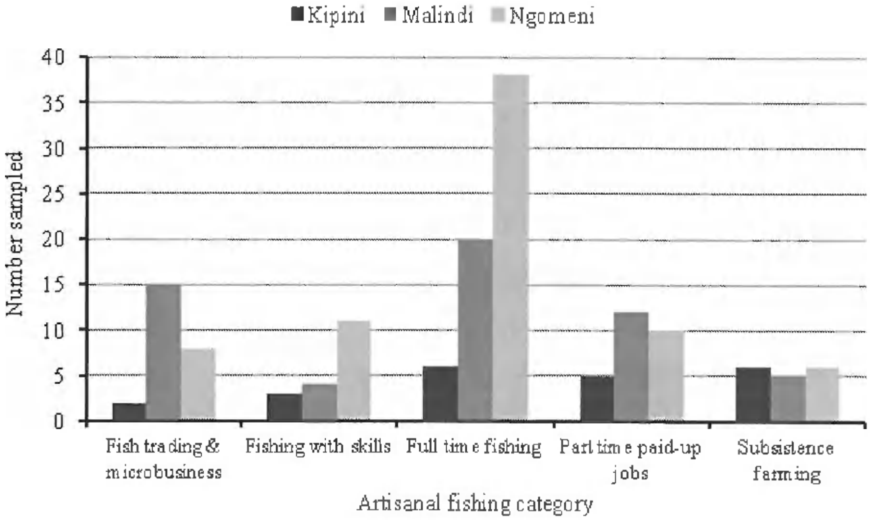

Figure 3. Artisanal fishing categories distinguished in the Malindi-Ungwana Bay, Kenya during the study period.

The number of fishers who also practiced subsistence farming was almost equally distributed among the three areas under study. Kipini and Ngomeni each had a total of 6 and Malindi had a total 5, which was only a small group overall (n = 17). Four factors in decreasing order were cited by the fishers as the major reasons why they engaged in fishing: for self employment (43%, n = 65), lack of education (25%, n = 37), lack of alternative employment (17%, n = 25), and due to apprenticeship passed on from father to son (16%, n = 24). The average age of fishers and the size of their households was lower (34 years, 4 people) for the full time fishers, while the oldest fishers (42 years on average) with largest households (7 people) were counted among the subsistence farmers. The mean age for fishers who also engaged in fish trading and microbusiness was also high (40 years on average) and a mean household size of 6 persons. Whereas, fishers with acquired skills and those in part time paid-up jobs each had a mean age of 36 years and a househlod size of 5 persons (Fig. 4).

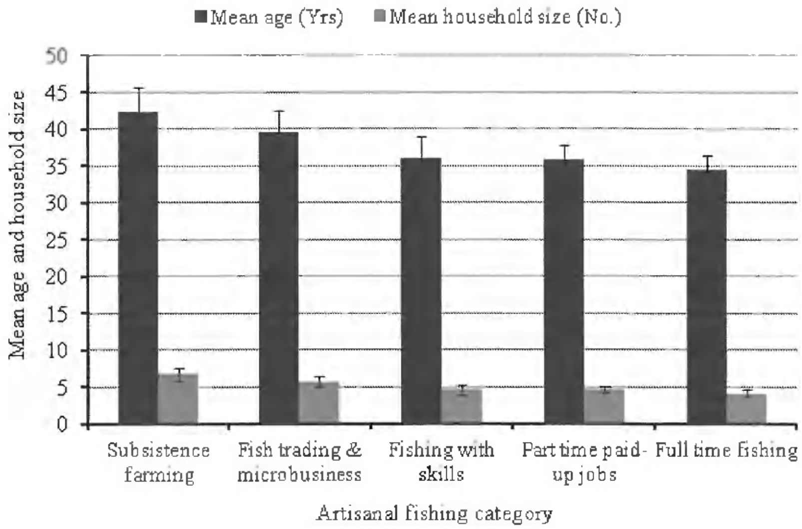

Figure 4. Mean age and household size (±SE) by fishing category in the Malindi-Ungwana Bay, Kenya.

Results of 2-way ANOVA indicated significant differences in mean age between fishing categories, and fishing areas. The same test showed no significant interaction effect (Table 3). The same test indicated no significant difference in mean household size between the fishing categories and between fishing areas, nor was there a significant effect due to fishing category with area interaction (Table 3). Most artisanal fishers from all fishing categories had no formal education and incomplete primary education (Fig. 5). Those who completed secondary and post secondary education were the least presented in all categories, (even in the fish trading categories where they were best represented).

Table 3. Results of 2-way ANOVA a weak significance difference in age between fishing category of fishers and a significant difference in age between fishing areas of fishers in the Malindi-Ungwana Bay, Kenya.

	Error df	Fishing category			Area			Interaction		
		df	F	p	df	F	p	df	p	p
Age	136	4	2.3	***0.05***	2	3.5	***0.03***	8	1.2	NS
Household size	136	4	1.7	NS	2	0.6	NS	8	0.5	NS

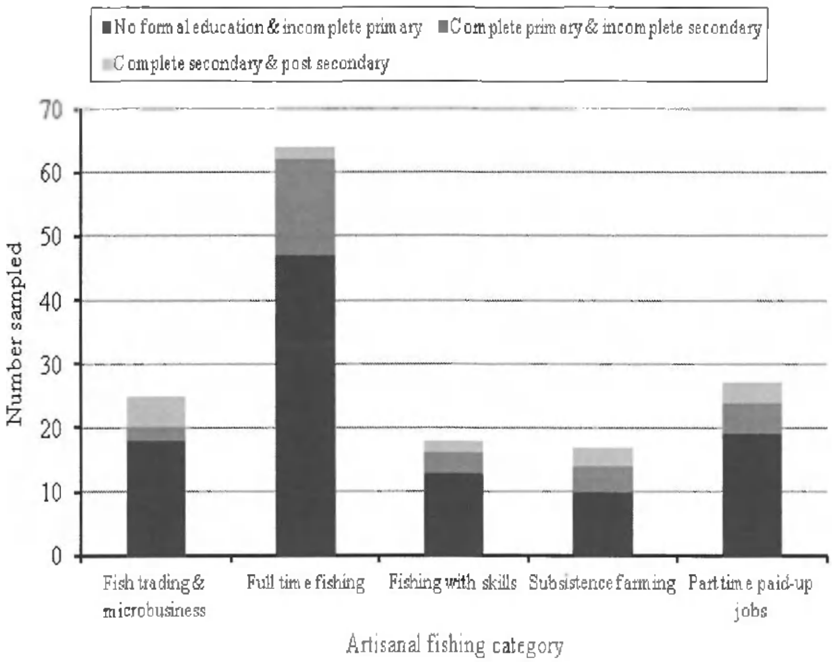

Figure 5. Education levels of artisanal fishers by fishing category in the Malindi-Ungwana Bay, Kenya.

Higher daily catches although with high fluctuations were associated with the full time artisanal fishers in Malindi with 29.3 kg/fisher.day on average, and those with paid-up part time jobs, in Malindi (20.9 kg/fisher.day on average) and Ngomeni (23.6 kg/fisher.day on average) (Fig. 6). Fishers in fish trading and micro-business, and those in subsistence farming from all areas had the lowest daily catches of < 5 kg/fisher.day on average. However results of Kruskal-Wallis indicated no significant differences in daily catches per fisher neither between the fishing categories nor between the fishing areas (Df = 4; Statistic = 3.898; p = 0.420 and Df = 2; Statistic = 0.037; p = 0.982 respectively).

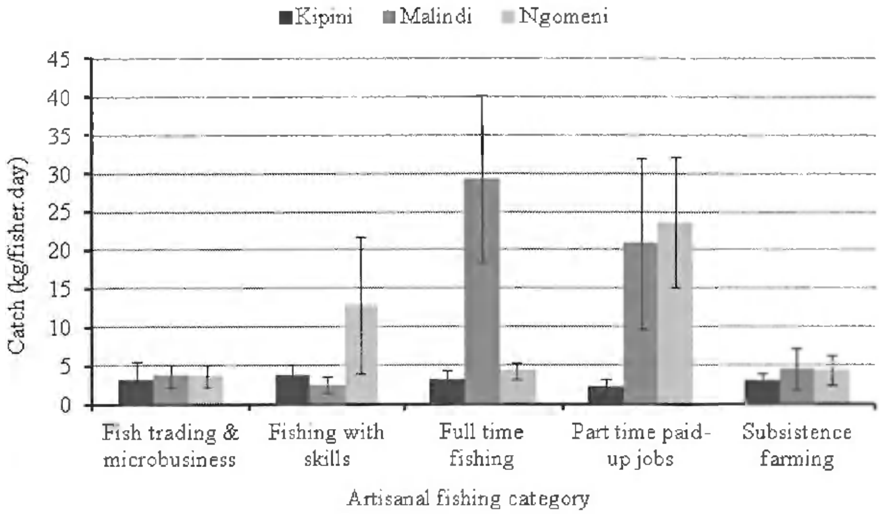

Figure 6. Mean daily catch (kg ± SE) per fisher by fishing category and area in Malindi-Ungwana Bay, Kenya.

Fishers in full time fishing from Malindi (25.9 USD/fisher.day) and Ngomeni (17.5 USD/fisher.day) and those who also earned by using acquired skills from Ngomeni (20.8 USD/fisher.day) had the highest daily income on average, and the lowest in those who engaged in part time paid-up jobs, and in fish trading and micro-business with less than 10 USD/fisher.day on average from all the areas (Fig. 7). These mean daily incomes were obtained from fish sales and in addition to earnings from alternative sources in the case of fishers who engaged in other activities. Results of 2-way ANOVA indicated no significant difference in mean daily income between fishing categories and between fishing areas (Df = 4; Error Df = 136; F = 0.451; p = 0.772 and Df = 2; Error Df = 136; F = 0.508; p = 0.603 respectively); nor was there a significant effect due to the interaction of fishing category with area (Df = 8; Error Df = 136; F = 0.367; p = 0.936).

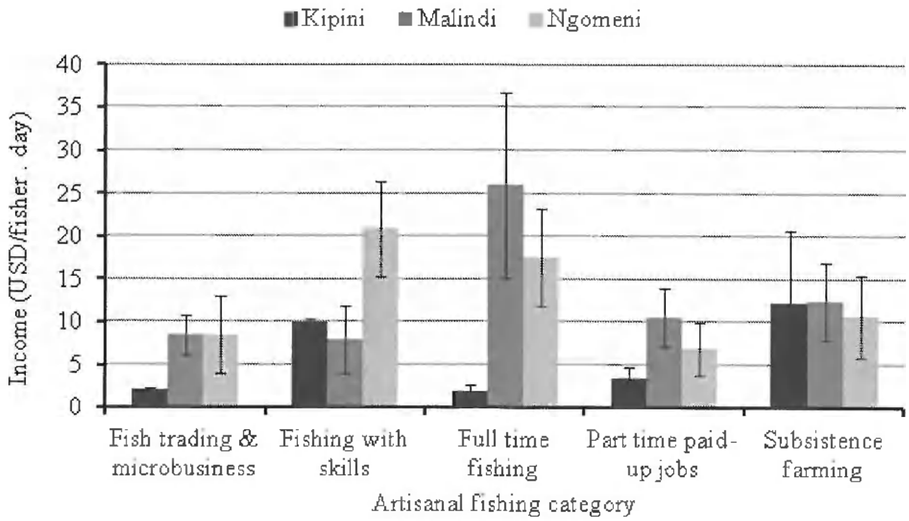

Figure 7. Mean daily income (USD/day ± SE) per fisher by fishing category and area in the Malindi-Ungwana Bay, Kenya.

6.4.2. Economic viability of the identified artisanal fishing categories

A total of 7 fishing gear types and 5 vessel/craft types common in all the artisanal fishing categories were identified with corresponding local market costs during the study time (Table 4). Each fishing category was associated with its characteristic composition of fishing gear and vessels which determined the level of investment in each artisanal fishing category and ultimately the corresponding Net Present Value (NPV) for each of the artisanal fishing category (Fig. 8). Results indicated highest NPV for artisanal fishers who engaged in fish trading and microbusiness. This was followed in decreasing order by those who engaged in part time paid-up jobs, those with some acquired skills, fishers in full time fishing, and lastly those who also engaged in subsistence farming.

Table 4. Average unit cost of artisanal fishing gear and vessel types during the study time with an annual maintenance cost of USD 258.06 for all net types* and USD 21.65 for all vessel types except surf board calculated based on 260 fishing days in a year.

Gear type	Length (m)	Average cost (USD)	Vessel type	Units	Average cost (USD)
Prawn seine*	100	28.9	Canoe	1	192.3
Handline	100	1.9	*Mashua*	1	3722.1
Monofilament gillnet*	100	61.4	Fibreglass boat	1	1861.0
Gillnet*	100	24.4	Outrigger	1	744.4
Longline	400	239.9	Surf board	1	310.2
Scoop net	_	22.7	_	_	_
Cast net*	_	55.8	_	_	_

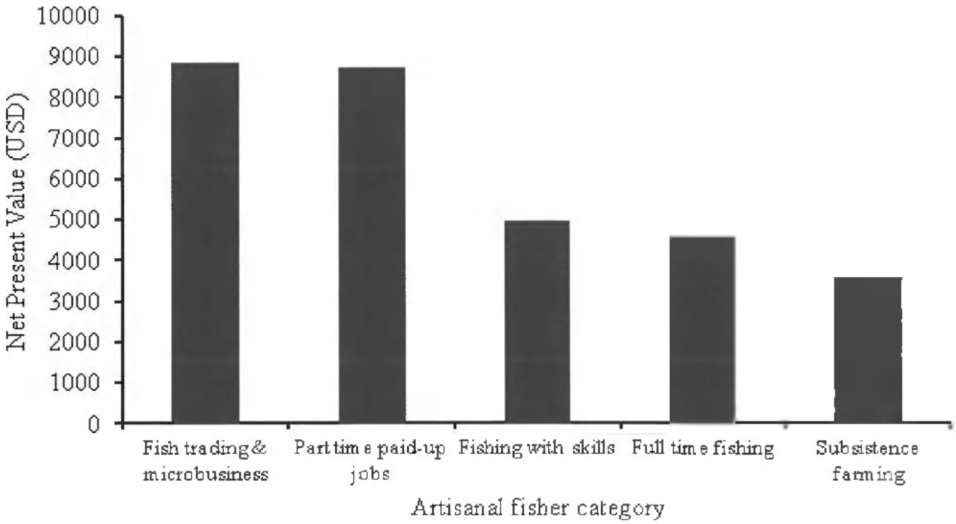

Figure 8. Comparison of Net Present Value (NPV) in US Dollars for ten year period between different artisanal fishing categories in Malindi-Ungwana Bay, Kenya beginning 2013.

6.4.3. Artisanal fishers' perceptions of shrimp trawling

The majority of the respondents perceived shrimp trawling with a negative impact (56.3%, n = 85), while a smaller group perceived shrimp trawling with no negative impact (43.7%, n = 66). The majority of artisanal fishers from all fishing categories except those who engaged in part time paid-up jobs perceived a negative impact of shrimp trawling mostly due to its associated damage to artisanal fishing gear, fish habitat, and excessive bycatches that are otherwise targeted by artisanal fishers (Fig. 9).

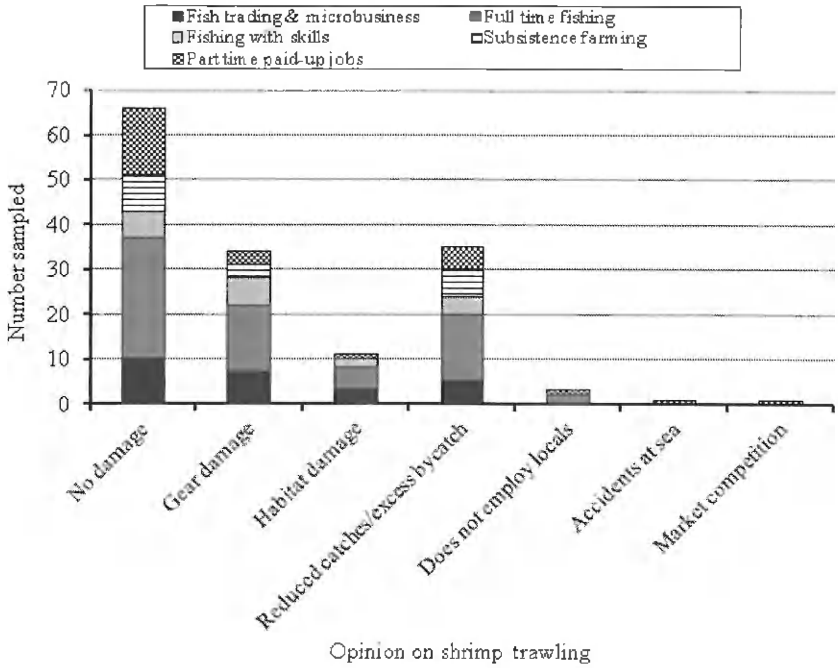

Figure 9. Opinion on the impact of bottom trawling of artisanal fishers by fishing categories in Malindi-Ungwana Bay, Kenya.

The majority of artisanal fishers in the category of 'no formal education and incomplete primary education' (61%, n = 65) perceived a negative impact of shrimp trawling, and only 39% (n = 42) perceived no impact. This was contrary to the thoughts of the fisher category of 'complete primary and incomplete secondary education' and that of 'complete secondary and post secondary education' where the majority 52% (n = 15) and 60% (n = 9) respectively perceived no impact of shrimp trawling.

Artisanal fishers' perceptions of shrimp trawling varied according to fishing area to some extent. Fishers from Kipini area were equally divided in their perceptions, with 50% (n = 11) perceived shrimp trawling had no impact and 50% (n = 11) perceived a negative impact. In the Malindi area, the situation was different in that majority of fishers (54%, n = 30) had a positive perception of shrimp trawling with 46% (n = 26) who had a negative perception. A different scenerio in Ngomeni where majority of the fishers (66%, n = 48) had a negative perception of shrimp trawling compared to a few fishers (34%, n = 25) who percieved no negative impacts.

Results of Chi-square tests however, indicated no significant difference in the perceptions of impact on shrimp trawling between fishing categories, between education levels of the artisanal fishers, and between fishers' locations ($p = < 0.05$ in all cases).

6.5. Discussion

6.5.1. Reasons for diversifying livelihoods

Like in many other tropical coastal artisanal fisheries, fishers in Malindi-Ungwana Bay, struggle to maximise their catches in order to improve their welfare, while fisheries resources keep on fluctuating and dwindling. Therefore, the artisanal fishers always have the option to fish more intensively by investing in acquisition of more vessels and gear, or in addition to their core fishing activity engage in other income generating activities (Hoorweg et al., 2008). This has been described as adaptive strategies (Allison and Ellis, 2001). Livelihood diversification is a widespread survival strategy by most rural households in Africa (Ellis, 2000), however focusing on farm households and pastoralists with little attention given to artisanal fishers' households (Allison and Ellis, 2001). The main reason for undertaking these alternative livelihoods is to limit the uncertainty associated with the highly seasonal nature of artisanal fisheries (Pontecorvo and Schrank, 2001). Diversification of livelihoods is generally expected to improve income, if not resulting in increase in income then at least resulting in a wider income spread, although specialization may be argued as a more efficient way of improving incomes (Hoorweg et al., 2008).

6.5.2. Artisanal fishers' livelihood diversification in Malindi-Ungwana Bay

This present study confirms that livelihood diversification is practiced in the Malindi-Ungwana Bay, ranging from part time paid-up jobs for some artisanal fishers, running of micro-businesses normally by family members, usually the fisher's wife (pers. obs.), to use of acquired skills such as boat building and repair so as to make an extra income. Most of these alternative livelihoods are carried out during the rainy season when the sea is too rough for fishing (Hoorweg et al., 2008), however, some fishers practice alternative livelihoods throughout the year (pers. obs.). As some fishers struggle to diversify livelihoods, the majority of them still have not found alternative options, where full time fishers formed the majority. Additional non-fishing activities such as boat construction and repair, and net mending are some of the jobs that need skill, and such skilled fishers are often highly demanded and therefore assured of an extra income. Although diversification of livelihoods by some artisanal fishers exists in the bay, financial wellbeing seemed not have significantly differed from those fishers who practiced full time fishing based on the results of daily net incomes and daily catches (Fig. 6 and 7).

Full time fishers are more likely to cause more pressure on fisheries resources compared to fishers who also undertake non-fishing alternatives. Full time fishers tend to have an increased dependency on fishing and therefore find it difficult to engage in alternative sources of income even during periods of resource scarcity, and this compromises resource sustainability (Allison and Ellis, 2001). Full time fishers in tropical artisanal fisheries are mostly local migrants operating outside their home areas with less interest for alternative livelihood, as opposed to their resident counterparts who are locals and more interested in other activities in addition to fishing (Allison and Ellis, 2001). In the Malindi-Ungwana Bay, most of the fishers were full time and the majority were indeed local migrants within their areas of operation.

The open access nature of tropical artisanal fisheries makes the majority of fishers, including those of the Malindi-Ungwana Bay to venture into fishing activity as a form of self employment. In addition, fishing generates money readily compared to other activities such as farming which is time consuming. The lack of formal education, has also made most of the fisher communities less competent in finding professional employment, and therefore end up in fishing as the last resort. Further more, fishing is considered a cultural activity for some coastal communities such as the *Bajuni* along the Kenya coast, and this has been passed on from generation to generation through apprenticeships (Glaesel, 1997). Activities other than fishing may not be easily available to some artisanal fishers due to lack of financial capital to start alternative commercial ventures, as most coastal communities are poor, and continue to depend on fisheries resources (Ellis, 1999). In order to reduce pressure on these resources, fisheries managers should aim at building capacity to the poor fishers so as to encourage diversification of income generating activities, although this may not significantly improve their economic gains as the results of this study indicate. At the same time, the expectation that improvements in fisher income will reduce pressure on resources has not been confirmed (Ellis, 2000).

6.5.3. The economic viability of different artisanal fishing categories

The artisanal fishery represents a small-scale economy and is vulnerable to production and maintenance costs, and local prices (Kronen, 2004). Therefore, the level of investment, maintenance costs of fishing gear and vessels, productivity (catch-per-unit-effort), and local market prices determines the economic viability of the identified fishing categories in Malindi-Ungwana Bay. These economic factors contributed in explaining why the full time fishers and fishers who engaged in subsistence farming recorded the lowest Net Present Value (NPV). This is because, full time fishing was associated with the highest maintenance cost of vessels and gear (Table 2), while fishing in combination with subsistence farming was among those categories associated with the lowest catch-per-unit-effort (kg/fisher/day, Fig. 6) and therefore less income. Therefore subsistence farming seemed not to be a better alternative livelihood source economically for the artisanal fishers, and the economic viability of full time fishing seemed to be improved by engaging in alternative livelihood sources other than subsistence farming. Although livelihood diversification should be encouraged, proper selection should be considered by the artisanal fishers so as to end up with the most economically viable livelihood alternatives.

6.5.4. Artisanal fishers' perceptions of shrimp trawling

A bigger proportion of artisanal fishers in the Malindi-Ungwana Bay perceived shrimp trawling with a negative impact, although this was not significantly different with those who perceived no impact. Localised strong opposition against shrimp trawling existed in Ngomeni area where some fishers own bigger fishing vessels and larger gillnets capable of fishing relatively offshore. In addition, majority of fishers in this area were least educated. The general feeling was that as long as trawlers were restricted to relatively offshore where they cannot cause conflict with the artisanal fishers, then the impact was perceived as not negative. Some fishers, especially those with formal education (complete secondary and post secondary) viewed trawling as a good opportunity if they could be allowed to participate fully in terms of decision making, and crew jobs availed to them. This is because, they felt that they indeed are qualified for such jobs and were not happy if these jobs were given to people who were not locals in the area. Contrary to fishers with no formal education and incomplete primary education whom majority was against the bottom trawling in the area although not significant, since they knew they did not qualify for the jobs due to lack of education or not meeting the required minimum education level. This outcome however, is limited to the 151 artisanal fishers interviewed which may not be a fully representation of the more than 3,000 artisanal fishers operating in the bay. The level of reliability of these assumptions is likely to change with a bigger sample size of the interviewees.

In conclusion, fishing is still a key source of livelihood for many artisanal fishers in the Malindi-Ungwana Bay as it is the most favourable source of self-employment and is still regarded as a cultural activity in some coastal communities. The lack of education and alternative employment by some artisanal fishers make them to engage in fishing since fishing skills are easily acquired and a high possibility of minimal capital is required depending on the category of fishing. This is because traditional fishing gear are simple, locally designed and inexpensive, accessible to many artisanal fishers, and can be operated without using vessels (Mangi et al., 2007). As long as livelihood diversification should be encouraged to fisher communities to better their income, full time fishers in this study compared to other fishers involved in additional non-fishing activities had similar daily catches and incomes. This study however, showed that full time fishing and fishing while at the same time engaging in subsistence farming may not be the best options in terms of economic viability. Artisanal fishers' perceptions of shrimp trawling in the bay did not vary with the type of fishing category, education level, and fishers' location, but did show a large variation in general from positive to negative. A similar study with a larger sample size of correspondents is however, recommended for future similar studies in the bay.

Acknowledgements

This study would not have been possible without the financial support awarded to the first author (CNM) by the VLIR ICP Ph.D. program in association with the Gent University, Belgium. Fridah Munyi, Faith Kimanga and Edward Waiyaki are thanked for their contribution in data collection while in the field. Our sincere thanks also go to all fishers who willingly accepted to share their information with us through the interviews which resulted into this publication. Finally, we thank the Director, Kenya Marine and Fisheries Research Institute (KMFRI) for provision of office transport during the entire study period.

1

Chapter 7

7. General discussion, conclusions and recommendations

7.1. Introduction

The practice of artisanal fishing along the Kenya coast dates back to the 16^{th} Century coinciding with the rise of the East African Indian Ocean trade that linked the East African coast to Arabia, Persia and India (Middleton, 2000; Stearns, 2001). Some of the existing old fishing villages include Ngomeni and Kipini along the Malindi-Ungwana Bay, and Vanga in the south coast, now gradually changing to modern life due to electricity supply and improved road access, but fishing remains a key livelihood. The coastline of Kenya is characterised by a fringing reef in most parts, and most of the productive coastal ecosystems (coral reefs, seagrass beds, mangroves, mud flats and salt marshes) are close to the shore giving the characteristic near-shore resource exploitation nature of the artisanal fishery.

Because of the high diversity of habitat types in the coastal environment, artisanal fisheries are also diverse and this determines the level and type of their exploitation (van der Elst et al., 2005). Several types of artisanal fisheries based on habitat type may be recognised. They include: the reef fishery, lagoon fishery, bay fishery, mangrove fishery, and inshore fishery which give the uniqueness of each fishery type. Artisanal fisheries are also decribed by their target species as well as fishing gear used. These features not only present a fascinating template for scientific endeavour, but also pose enormous challenges to protect biological diversity and sustainable development (van der Elst et al., 2005). Within the Malindi-Ungwana Bay, distinct sub-fishery types exist: the bottom trawl shrimp fishery, the artisanal finfish fishery, the artisanal shrimp fishery, and the artisanal mangrove crab fishery among others. The classification of fishery types is important for their development and management requirements for sustainable utilisation. As a result of the uniqueness of each fishery, specific management plans could be developed for each in line with the Ecosytem Approach to Fisheries (EAF). On the other hand, Kenya does not have the capacity to manage and exploit the offshore barely unknown fisheries resources within its Exclusive Economic Zone (EEZ). Despite these specific fishery types and having been in existence for several decades, the management of Kenya coastal fisheries is still facing many challenges as found out in this present study. The guidelines for an EAF management plan are: a comprehensive background information of the fishery, clearly defined and working objectives, management measures, decision rules, access rights, evaluation of management, monitoring, control and surveillance, communication, and review of the relevant areas of research that would lead to improved ability to implement effective EAF (FAO, 2005).

7.2. The Malindi-Ungwana Bay fisheries assessment

This present study gives a systematic assessment of the Malindi-Ungwana Bay fisheries in Kenya for the first time. This assessment of the bay's fisheries resources covers the period between 2001 and September 2006, a period of active bottom trawling before the ban, and a period of six years after trawling ban. The Malindi-Ungwana Bay is important both for the artisanal sub-sector and the semi-industrial bottom trawl fishery. Artisanal fishing as well as bottom trawling were practiced for several decades since the early 1970s, and since then the fisheries management followed the conventional top-down approach, until after 2000 when co-managment was introduced in Kenya. Co-management is a shared responsibility for the management of a resource between the government and resource users, stakeholders or local communtiy (Berkes et al., 2001). The co-management approach during this period was not developed as its legal management structure, commonly known as the Beach Management Unit (BMU) was at its initial stages of formation. As a result, there were increased conflicts between the artisanal fishery and bottom trawling fishery. In addressing these problems, recommendations for trawl bycatch reduction such as minimum trawling distance, closed trawling season, prohibition of night trawling, and the mandatory use of Turtle Exluder Devices (TEDs) were proposed, but implementation and compliance by the trawlers was poor due to lack of enforcement (Fennessy et al., 2004; Mwatha, 2005). This culminated into a ban of the bottom trawling between September 2006 and July 2011 which paved the way for the consultative formulation of the present shrimp fishery management plan which came into existence by July 2011.

Although a management plan is now in place, it is evident that this plan did not follow all the above mentioned guidelines required for an Ecosystem Approach to Fisheries (EAF). Ecosystems are complex and dynamic natural units that produce goods and services beyond those of benefits to fisheries. Because fisheries have a direct impact on the ecosystem, which is also impacted by other human activities, they need to be managed in an ecosystem context. The goals of EAF are to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic, and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries (FAO, 2003). According to the FAO (2005), EAF operates under five key principles. These are: the management of fisheries to limit their impact on the ecosystem to an acceptable level, maintenance of the ecological relationships between species, compatible management measures across the entire distribution of the resource, precaution in decision making due to inadequate knowledge on the ecosystem, and the inclusion of both human and ecosystem well-being and equity in governance. Therefore, in order to embrace these key principles, the development of a management plan to suit the EAF requirements, specific guidelines have to be followed. The EAF thus intends to foster the use of existing management frameworks, improving their implementation and reinforcing their ecological relevance so as to achieve sustainable development (Garcia and Cochrane, 2005). For the case of Malindi-Ungwana Bay shrimp fishery management plan, the EAF guidelines that were not followed include the **background** of the fishery which did not include a description of the trawling and artisanal fishing activities, resources and the ecosystem, in addition to the ecological issues and challenges. **Evaluation of management** is another EAF guideline that was not observed in the shrimp fishery management plan. The management plan did not include any information on the status of the stocks including bycatch species composition, state of the ecosystem and socio-economic characteristics. The development of the Malindi-Ungwana Bay shrimp fishery management plan also failed to include the **review** guideline of the EAF that pin points the relevant areas of research that would lead to improved ability to implement effective EAF. Such areas that were not addressed include regular monitoring of the ecosystem and socio-economic aspects. The discussion that follow shows how this present study has contributed to valuable information that would assist in the revision of the shrimp fishery management plan in achieving the EAF requirements for effective management of the bay's fisheries resources.

7.2. Status of the Malindi-Ungwana Bay fisheries before the ban

Chapter 2 of this thesis describes the status of the Malindi-Ungwana Bay both the artisanal fishery and the bottom trawl fishery before the trawl ban. The information on the status of the fisheries resources in the bay in this present study has been limited to about six years between 2001 and September 2006, a time of active bottom trawling in the bay. So far, this is the only review conducted after more than three decades of active bottom trawling before the ban in September 2006. Trawl catch data before 2001 were not readily available and therefore, the earlier status of the bay's fisheries resources could not be established in this study. Also there was no appropriate data to evaluate the ecosystem in order to provide a detailed background status of the bay in totality.

The artisanal gear destruction by trawlers was easily noticeable through reported cases and complaints of failure to compensate the affected artisanal fishers (Fennessy et al., 2004).

The perceived reduction of artisanal catches due to excessive production of both discarded and retained trawler bycatches of especially finfish were documented using the 2001-2006 trawling data. In this review, four groups of landings were anlysed for trend in terms of total weight and catch-per-unit-effort (CPUE). Being a data-limited fishery, the use of catch/landings and effort data was the most practical option for studying the effects of trawling of shrimps and bycatch populations (Sparre and Venema, 1989). These landings were: the artisanal shrimps, artisanal catches of mostly finfish, bottom trawl shrimps and fish bycatch. The evaluation of these landings indicated a clear trawling impact because of the reduced trawl shrimp landings with a relatively constant trawling effort of between 4 and 5 trawlers during the period under investigation (Chapter 2). Although the artisanal catches were always higher than the trawl bycatch, a dramatic decrease of artisanal catches was experienced from 2004 upto the time of trawling ban in September 2006. As these catch data were aggregated and only available at higher taxa (mostly family level), it was not possible to identify the composition of both shrimps and finfish trawl bycatch at species level, but an indication of total trends was possible and composition by family or higher taxa was investigated. Aggregation of catch data across all species does not reveal trends in the abundance of individual species, as total catch rate often tends to remain constant despite varying trends in the abundance of these species (van Oostenbrugge et al., 2002). This assessment in Malindi-Ungwana Bay revealed that spatially, shrimp catches were higher in the inshore areas than offshore, in reference to the location of the two estuaries of the Sabaki and Tana rivers. This also has the indication of how finfish bycatch was distributed in the bay.

The composition of the artisanal catches also showed how important especially the Tana Delta ecosystem was. More abundant freshwater fish families were associated with the Tana Delta by virtue of its extensive area and oxbow lakes before draining into the ocean at Kipini, north of the Malindi-Ungwana Bay. This means that, both the marine and freshwater catches play an important role in the socio-economic well-being of the artisanal fishers in the bay as results of this study indicate. The freshwater fish families in the Tana Delta have the potential of improving the coastal artisanal catches, and at the same time reducing pressure on the inshore marine resources. The freshwater fish families in the delta are however, under threat, due to lack of adequate river discharge management. This is because through the Ministry of Irrigation, the Kenya Government has initiated irrigated agriculture in the lower Tana Delta diverting some of the river waters to crop fields. As a result, some of the oxbow lakes receive inadequate water, coupled with dry weather spells. Due to its ecological and socio-economic importance, the Tana Delta has recently been designated the newest Ramsar site in Africa and indeed the world. The delta is the second most important estuarine and deltaic ecosystem in Eastern Africa, which permits diverse hydrological functions and a rich biodiversity (Ramsar Convention on Wetland Secretariat, 2012). Chapter 2 of this thesis therefore, contributes some relevant information on the EAF guideline on **background** of the Malindi-Ungwana Bay fishery that was not included in the development of the shrimp fishery management plan.

7.3. Status of the Malindi-Ungwana Bay artisanal fisheries after the ban

Part of Chapter 2 and the entire Chapter 3 contribute to information on the EAF guideline on **evaluation of management** under different aspects. All the information is in relation to the fishery status after the trawling ban. After two years of the trawling ban, artisanal total landings showed an increase. No detectable changes were however, associated with the artisanal shrimp landings before and even two years after the trawling ban (Chapter 2). As these total artisanal shrimp landings remained unchanged, it therefore suggests that the existing patterns of exploitation may be sustainable. This means that, the artisanal shrimp fishery was not affected by the trawling activity as artisanal shrimp fishing is conducted in shallower fishing grounds mostly in mangrove creeks of the Tana and Sabaki estuaries which are away from the trawling grounds. Also the artisanal shrimp fishing, unlike bottom trawling is highly affected by the seasons. Most artisanal shrimp fishing takes place during the dry Northeast Monsoon (NEM) season and the activity along most parts of the bay completely stops during the wet Southeast Monsoon (SEM) season. As shrimp catches for the SEM season are minimal, the data reported in the artisanal shrimp fishery are most likely for the NEM seasons only. During the wet seasons, the mangrove creeks and river estuaries are filled with freshwater input thereby lowering the salinity level. This condition offsets the movement or migration of the sub-adult shrimps offshore where they grow to full adult and spawn. After spawning, the larvae drift back to the creeks and nearshore areas where they grow into sub-adults before the process is repeated (Garcia and le Reste, 1981; King 1995). This life cycle of shrimps (Fig. 1) may also have an impact on the total artisanal shrimp catches, as artisanal fishers are restricted in movement due to lack of appropriate fishing gear and vessels.

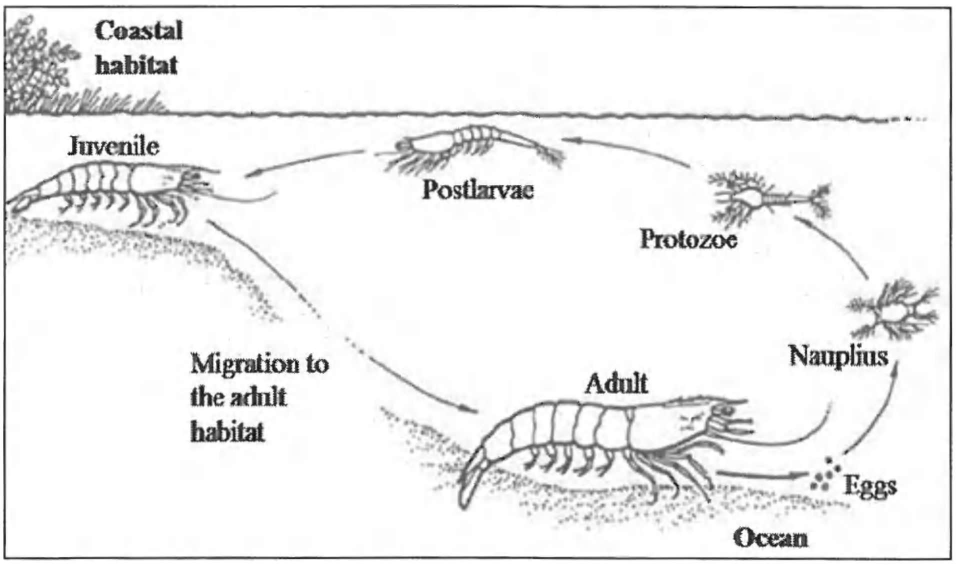

Figure 1. General life cycle of a shrimp (Garcia and le Reste, 1981; King, 1995).

It was also necessary as the ban was still effective, to conduct shore-based artisanal catch assessment of finfish at species level, linking their exploitation in the bay with defined vessel-gear combinations for data at a finer scale (**Chapter 3**). Elucidating trends in catch rate and composition is important to evaluate the state of fish stocks and guide future fisheries management action in any developing tropical fishery. The mean trophic levels for the most popular vessel-gear combinations used in the bay, determined the level of fisheries exploitation (Davies et al., 2009). The status of a fishery in terms of its exploitation is determined by the value of the mean trophic level of its stocks. Lower mean trophic levels signify an overfished fishery, as artisanal fishers tend to target catches in the higher trophic level. A rapid decline in predatory fish species will lead to shifts in fish targeting from higher to lower trophic level species. In the Malindi-Ungwana Bay, relatively high mean trophic levels of the artisanal catches were recorded. This was a good sign of an ecosystem integrity of the fishery after the bottom trawling ban. Given that the artisanal finfish catches of the Malindi-Ungwana Bay were composed of high trophic level species, this indicates that the artisanal fisheries were lightly exploited or had recovered after the bottom trawling ban. This information on the status of artisanal fisheries exploitation was based on catch assessment data collected three years after the trawl ban. Such data were not available before the trawl ban and therefore, as the ban is now lifted, a similar study will be necessary so as to verify the exploitation status of the artisanal fisheries. Other indicators for fisheries exploitation that were also generated in this study were species composition, catch-per-unit-effort (CPUE), and the mean total lengths by vessel-gear combinations. Since fishing is an extractive activity, these indicators are likely to change if the fishery is subjected to over-exploitation. Changes in CPUE may arise not only from changes in stock biomass but from changes in catchability, and it is also possible that both factors simultaneously influence the realtionship between CPUE and fishing effort. Over fished fisheries area associated with reduced species diversity, CPUE and smaller individuals. These indicators are best candidate information for the EAF guideline on **review** as they can be monitored over time to provide information on the bay's fisheries status.

Fishing is selective and has the potential to change populations. Many fishers target a particular species or group of species and target large adults as opposed to juveniles. It is well known that different fishing gear catch different fish sizes in the same area, in what has been described as selectivity in Chapter 3. This selectivity is also determined by the different fishing vessels used and the duration of fishing activity at sea. In spite of this potential for selectivity, evidence for genetic changes due to fishing, especially in marine populations has been limited (Smith, 1994).

7.4. Status of the Malindi-Ungwana Bay bottom trawl fishery after the ban

The Malindi-Ungwana Bay fishery including the North Kenya Bank, provides some of the most rich fishing grounds where both finfishes and shellfishes have been exploited for several decades both for local and export markets (Nzioka, 1979; Mwatha, 2005). Like the Sofala Bank in Mozambique, Rufiji Delta in Tanzania, and Tugela Bank in South Africa, the Malindi-Ungwana Bay has been well known for its bottom trawl shrimp fishery in the Western Indian Ocean (WIO) region (Olbers and Fennessy, 2007). The bay receives nutrients and terrigenous sediments input from the Tana and Sabaki rivers (Abuodha, 2003; Kitheka, 2013). Seasonal exports of nutrients stimulate phytoplankton and benthic microalgal production, which are important primary sources in coastal food webs (Loneragan and Bunn, 1999). The freshwater input and sedimentation do not favour the growth of corals making the bay the only trawlable area in Kenya, and its muddy bottom a conducive habitat for crustaceans (Abuodha, 2003; Kitheka et al., 2005). After a heavy river discharge, especially during the Southeast Monsoon (SEM) season, the sediment plume extends to more than 5 km offshore (Kitheka et al., 2005). Past studies have shown that fish catches increase in the years following heavy river discharge (McClanahan and Young, 1996). The productivity of the bay is also triggered by water movement as a result of the monsoon winds and tides. This is in addition to ocean currents: the East African Coastal Current (EACC) flowing northwards and meeting the Somali Current (SC) flowing southwards, results into the South Equatorial Counter Current (SECC) that causes upwelling of nutrients in the bay (Kitheka, 2005). River discharge has long been recognised as one of the factors that contributes to the high productivity of estuaries (Loneragan and Bunn, 1999). There is little evidence of the contribution of terrestrial carbon input from river discharge on coastal food webs, but such exported nutrients may stimulate *in situ* production in estuaries favourable for the growth of fish and crustaceans. Fluctuations in salinity and turbidity may influence the extent of available habitat for marine organisms and therefore affect their distribution and/or catchability (Loneragan and Bunn, 1999).

Experimental bottom trawl surveys were conducted during the dry NEM and wet SEM seasons (**Chapters 4 and 5**) and provided status of the shrimps and finfish bycatch stocks in the bay. These surveys provided information on the abundance, composition, diversity and distribution patterns. Again this information adds to the EAF guideline on **evaluation of management** for the Malindi-Ungwana Bay shrimp fishery management plan. The information provided from these trawl surveys give an indication on the amount and how the fisheries resources are distributed in the bay six years of bottom trawling ban. For instance, from the surveys, it was evident that the Sabaki and Tana estuaries and nearshore areas harbour the most shrimp populations than the offshore areas. Coincidentally, these are the same areas where higher finfish bycatch populations were, and therefore identified as the potential areas of resource overlap between the bottom trawl fishery and the artisanal fishery. This means that before the bottom trawl ban, the Sabaki and Tana estuaries and nearshore areas were most likely the centres of conflict and not the entire bay.

The species diversity of shrimps and finfishes in the bay was area-dependent. The inshore area of the bay was richer in finfish than offshore. This was attributed to the existence of favourable inshore habitats mostly muddy and sandy bottom, and the presence of crustacean species particularly the penaeid shrimps that are prey species to most finfish species (van der Elst, 1981). Most finfish bycatch species were evidently less abundant in the offshore area where shrimps were absent (Chapter 4; Munga et al., 2013). Specific associations between shrimp species and among fish taxa have been linked to predator-prey relationship thereby affecting the structure of populations. According to de Freitas (2011), *Fenneropenaeus indicus* was reported to be associated with the fish species *Rastrilleger kanagurta, Lutjanus* sp., *Hilsa kelee* and the flatfish *Solea* sp. Further findings by this author indicate that the most important predators of adult *F. indicus* are *Scomberomorus commersoni, Otolithes ruber, Pomadasys maculatus, Terapon jarbua, Pelates quadrilineatus* and *Caranx* sp. and these finfish species were most abundant in the inshore Malindi-Ungwana Bay (Chapter 5). Studies of stomach content analyses of *O. ruber, T. jarbua, Platycephalus* sp. and *Sillago sihama* have yielded positive identifications of *F. indicus* pre-adult forms (de Freitas, 2011). Other fish species found in nursery areas as predators of *F. indicus* juveniles are *Pellona ditchela*, *Thryssa vitrirostris* and *Leiognathus equulus* (de Freitas, 2011; Macia, 2004).

Only five shallow water penaeid shrimp species have been documented so far in the bay, and catches have been dominated by *Fenneropeneaus indicus* and *Penaeus monodon* (Fulanda et al., 2011; Munga et al., 2013). However, recent and ongoing genetic studies have indicated that *Metapenaeus stebbingi* Nobili 1904 co-occurs with the other five shallow water penaeid shrimp species bringing the number to six species in the bay (Mkare, 2013). For sustainability of the bottom shrimp fishery and other crustacean resources in the bay, diversified and sustainable harvesting approaches are needed. A shift to further offshore and relatively deeper resources is a possible strategy although it also has to be considered with care. Commercial crustacean species further offshore Malindi-Ungwana Bay are available (Kimani et al., SWIOFP unpublished report). These include shrimp species: *Heterocarpus woodmasoni, Penaeopsis balssi* and *Plesionika martia.* Lobsters species include: *Metanephrops mosambicus, Puerulus angulatus* and *Linuparus sumniosus*, and the offshore crab species *Chaceon macphersoni*. Furthermore, the determination of the importance of shrimp species to total catches may not have been accurate due to behavioural differences of the different species. Burrowing species such as *Penaeus semisulcatus* and *Penaeus japonicus* are likey to have lower catches in day trawls, since these species are active only at night when trawling is prohibited. Therefore, future experimental stock assessment surveys in the bay should include night time sessions to compliment such likely differences.

7.5. The socio-economic importance of artisanal fishing in Malindi-Ungwana Bay

Tropical artisanal fisheries represent one of the primary resources utilised by the coastal communities. Along with other coastal resources, the artisanal fisheries have supported coastal communities for generations and are a source of sustenance and income. However, as is the case in many tropical regions, increasing population, poverty, lack of alternative livelihoods and the effect of rapid coastal development have all placed unprecedented pressure on the fisheries resources and therefore, the need for effective management. Compared with the ecological investigation of fish populations, the socio-economic aspects of fisheries have been largely neglected in fisheries assessment and management (Cinner and McClanahan, 2006). For success of fisheries management, compliance by resource users is important. This compliance can only be achieved if resource users are involved and participate in the development of fisheries management plans as a requirement of the Ecosystem Approach to Fisheries (EAF). Fishers' knowledge have become part and parcel of formulation of fisheries management and therefore, the need for their involvement (Johannes et al., 2000).

The socio-economic study in Malindi-Ungwana Bay elucidated the social and economic status of fishers. Socially, fishers have families to cater for their needs. In order to satisfy family needs, fishers tend to invest more in time and resources, as well as diversifying livelihood options. It is also typical of fishers to diversify livelihood sources due to the seasonal nature associated with artisanal fishing. Artisanal fishers use low level of fishing technology and this influences the low productivity associated with this sub-sector. Fishing activity is manually operated and in most cases the fisherman and sometimes members of the family are involved in the daily fishing activities. Livelihood diversification was eminent in the Malindi-Ungwana Bay. The majority of fishers, more than half who were interviewed were associated with alternative livelihoods although fishing remained the key source of income earner. Those who did not have alternative livelihood sources also indicated their interest in diversifying. As diversification was common among artisanal fishers in Malindi-Ungwana Bay, it was found out that not all alternative options were economically viable and therefore productive to these fishers. Therefore, fishers were still threatened by the perceived negative impact of trawling as fishing still remained the major source of their livelihood.

7.6. Management of fisheries resources in Malindi-Ungwana Bay

The fisheries resources conflict in Malindi-Ungwana Bay between the artisanal and bottom trawling sub-sectors was ostensibly due to the perceived environmental degradation, production of excess trawl bycatches, and the damage of artisanal fishing gear by the trawlers (Fulanda et al 2011; Munga et al., 2012a). These conflicts between the two fishery types were experienced because trawlers contravened measures that existed by then by trawling in fishing grounds also accessed by artisanal fishers (Government of Kenya, 1991). The retained trawl bycatches especially of finfish also found their way to the local fish market which reduced fish market prices. This was again a problem for the artisanal fishers because they were forced to equally sell their catches at lower prices (Ochiewo, 2004). Therefore, so as to solve these conflicts, the government first reacted by introducing some management measures on trawling including closed season and use of Turtle Excluder Devices (TEDs), but these were poorly complied with by the trawlers. The government finally reacted with a ban of trawling in September 2006 and formulated the shrimp fishery management plan. The broad objective of this management plan is to ensure the continuation of a biological sustainable and economically viable shrimp fishery in order to benefit all Kenyans (Government of Kenya, 2011). The major weakness of this management plan is that it was formulated without adequate scientific information and data, and did not follow guidelines as required by the Ecosystem Approach to Fisheries (EAF). However, the management plan clearly stipulates such management measures as offshore trawling limit of 3 nm, restriction of 4 vessels of 300 Gross Registered Horse Power (GRHP) at 3 nm offshore and 4 vessels of more than 300 GRHP at 5 nm offshore, enforcement of the trawl closed season (1st November to 1st April every year), bycatch regulation using Turtle Excluder Devices (TEDs), Bycatch Reduction Devices (BRDs), mesh sizes regulation, closed areas, and prohibition of night trawling. All these are viable measures and will only be effective with all stakeholders' compliance, and the need to be supported with data and scientific information that has been provided for in this study.

The artisanal fishery in Malindi-Ungwana Bay does not utilise the relatively deeper and offshore fishing grounds due to lack of capacity. Therefore, the solution to have a conflict free bottom trawling of shallow water penaeid shrimps, in Kenya and other developing tropical fisheries remains a challenge. The shrimp fishery management plan is expected to guide the sustainable trawling of shrimps and reduce conflicts in the bay. Attempts have been tried world-wide to make bottom trawling more environmental friendly (especially to reduce bycatch) using both legislative and technological initiatives. The legislative initiatives include the use of seasonal closures/areas, minimum trawling distance and/or depth, restriction of trawling permits, ban on nocturnal trawling, annual rotation of spatial effort zonation, restriction on mesh size, and especially in South Africa, the prohibition of sale of certain fish species occurring as trawl bycatch. The technical intiatives include compulsory use of TEDs on trawl nets especially in Kenya, Tanzania, Mozambique and Madagascar; the use of BRDs in South Africa, restrictions on mesh and trawl gear sizes in Madagascar and South Africa. All these initiatives are instrumental in the sustainable management of trawl fish bycatch however, according to Fennessy et al., (2008) the compliance of such initiatives in the Western Indian Ocean (WIO) countries have been limited due to lack of political and industrial interest, and the will to resolve the bycatch problem in addition to lack of adequate technical capacity. Since trawl bycatch abundances are higher inshore than offshore and mostly include finfish species which are also a target to artisanal fishery (**Chapter 5**), then the stipulated measure on limitation of trawling distance of 3 nm offshore in the shrimp fishery management plan seems to be feasible, since further offshore shrimp abundances are much lower (Munga et al., 2013). The 3 nm offshore distance trawl limit may also reduce direct conflicts with artisanal gear damage, since majority of the artisanal fishers operate in waters of less than 3 nm. The proposed trawling of 5 nm offshore and beyond should be handled with careful since the abundance of shallow water penaeid shrimps in the bay decreases with increasing depth and away from the shore (Chapter 4; Munga et al., 2013).

The management measure on the proposed closed areas within the bay especially, in inshore areas may not be feasible socially to the artisanal fishers. Artisanal fishers in Kenya have a negative attitude towards marine closures with the perception of being eliminated from their fishing grounds (Munga et al., 2010). However, the use of new community-based approaches such as Locally Managed Marine Areas (LMMAs) seem to gain acceptance in some areas along the Kenya coast. **Chapter 5** of this thesis on finfish bycatch species distribution indicated that different species have different ability of distribution in the bay in terms of depth and distance offshore. The proposed closure will only be effective to species that have a limited distribution such as *Lobotes surinamensis* but not to species with a wider distribution such as *Otolithes ruber* within the bay.

Gear-based management of the artisanal fisheries has some limitations since species composition of a gear is dependent on the vessel type used in addition to other factors such as seasons, fishing grounds and frequency of use (Hoorweg et al., 2008). In other words, gear-based management alone may not be adequate. The use of multiple gear also makes monitoring and management cumbersome for the artisanal fisheries in addition to factors such as change in fishing effort and weather patterns which affect artisanal catches. Therefore, the proper identification and use of specific vessel-gear combinations as fishing units would make management and monitoring of artisanal fisheries much easier, realistic and achievable.

The highest fishing pressure for artisanal fisheries in Kenya is experienced in the inshore and relatively shallow fishing grounds. This is because, most fishers lack proper vessels to enable them access far off and less exploited fishing grounds. One way of sustaining artisanal fisheries therefore, is to lessen the pressure on the already overfished inshore areas by enablishing fishers to relocate to relatively offshore fishing grounds and this would ultimately improve catches both by volume and quality. Ochiewo et al., (2010) in a study of south coast Kenya artisanal fishery indicated an increase in fish catches when fishers used motorised *mashua* boats with effective gear such as ring nets and long lines.

7.7 Main conclusions of the study

- Bottom shrimp trawling in the bay before the September 2006 ban indicated some negative impact on the artisanal catches, and the target shrimp catches but not on artisanal shrimp catches.
- The *mashua*-gillnet, canoe-gillnet and foot-seine net were singled out as the suitable fishing units for monitoring the artisanal fisheries in Malindi-Ungwana Bay by virtue of landing highest mean trophic level and largest sized individuals for the *mashua*-gillnet, and highest number of fish species caught for the canoe-gillnet, and smallest sized individuals for the foot-seine net.
- Shrimp catch rates and biomass in Malindi-Ungwana Bay, decreased with increase in depth and away from the shore, and were significantly higher during the wet Southeast Monsoon (SEM) season than the dry Northeast Monsoon (NEM). Also the Tana and Sabaki estuaries significantly differed in shrimp composition, with the shallower and more turbid Tana estuary characterised by more abundant *Fenneropenaeus indicus* and the deeper and and less turbid Sabaki estuary characterised by more abundant *Penaeus semisulcatus*.
- The size at first maturity (L_{50}) was determined for *Fenneropenaeus indicus* (37.4 mm), *Penaeus monodon* (41.9 mm), *Metapenaeus monoceros* (36.0 mm) and *Penaeus semisulcatus* (33.4 mm) as a biological indicator for monitoring.
- The finfish species: *Galeichthys feliceps, Pellona ditchela, Johnius amblycephalus, Leiognathus equulus, Pomadasys maculatus, Otolithes ruber* and *Lobotes surinamensis* were more abundant both in artisanal and trawl bycatches and therefore, the potential species for resource overlap and conflict between bottom trawling and the artisanal fishery in the inshore area of the Malindi-Ungwana Bay.

- The economic viability of artisanal fishing increased with additional livelihood sources such as fish trading and micro-business, part time paid-up jobs, and use of acquired skills for making extra income, but not with subsistence farming or when full time fishing was undertaken alone.
- Majority of artisanal fishers from all fishing categories except those who engaged in part time paid-up jobs perceived a negative impact of shrimp trawling mostly due to its associated damage to artisanal fishing gear, fish habitat, and excessive bycatches that are otherwise targeted by artisanal fishers.

7.8 Future recommendations and considerations

The Malindi-Ungwana Bay will continue to be an important fishery in Kenya. This is by virtue of its geographical location: the presence of the two rivers, diverse ecological habitats, the Tana Delta as a Ramsar site, and the presence of ocean currents that are important for distribution of nutrients and plankton. There is still a great hope of achieving better management of fisheries resources in the bay. This is because Kenya has recognised the value of fisheries resources to the contribution of its national food security and Gross Domestic Product (GDP), in addition to the presence of legislative laws and regulations to govern management. However, this will only succeed if the following future recommendations and considerations are implemented:

- A thorough revision of the shrimp fishery management plan taking into consideration the findings of this study for inclusion of especially information that contribute to the EAF guidelines on **background**, **evaluation of management** and **review**. This is because the shrimp fishery management plan was formulated with relatively little scientific information available by then, and without following the EAF guidelines which is the current world-wide accepted management approach.

- Regular monitoring for long term data of fish and shrimps of the identified biological and fishery aspects of mean sizes, mean trophic levels, catch composition, catch-per-unit-effort and size at first maturity (L_{50}) using the proposed *mashua*-gillnet, canoe-gillnet, foot-seine net and bottom trawl.
- Use of genetic techniques to unravel the exact number of species of penaeid shrimps in the bay. This process has already been started with one extra species *Metapenaeus stebbingi* having just been identified to co-occur with the five other penaeid shrimps (*Fenneropenaeus indicus*, *Metapenaeus monoceros*, *Penaeus monodon*, *Penaeus semisulcatus* and *Penaeus japonicus*).
- The nature of artisanal fishing operation in nearshore is not sustainable due to increased pressure on the resources, weather and seasonal changes. The Kenya Government through the Fisheries Department, should initiate a program to equip artisanal fishers with modern fishing vessels and gear to enable them access offshore resources so as to prevent over-exploitation of the nearshore fisheries resources. This will also help to improve the living standard of the local fishermen through improved catches. Also continued implementation of aquaculture project under the government initiated Economic Stimulus Programme (ESP) to increase food self sufficiency.
- Enforcement of the minimum offshore trawling distance of 3 nm, regular use of onboard observers on trawlers to document target and bycatch species, mandatory use of Bycatch Reduction Devices, observation of the closed trawl season, and sustained prohibition of night trawling unless under research purposes.

References

Abuodha, J.O.Z. (2003). Grain size distribution and composition of modern dune and beach sediments, Malindi Bay coast Kenya. Journal of African Earth Sciences 36: 41-54.

Allison, E.H., Ellis, F. (2001). The livelihoods approach and management of small-scale fisheries. Marine Policy 25: 377 – 388.

Alverson, D.L., Freeberg, M.H., Pope, J.G., Murawski, S.A. (1994). A global assessment of fisheries by-catch and discards. FAO Fisheries Technical Paper. No. 339. Rome, FAO. 233 pp.

Appeltans, W., Bouchet, P., Boxshall, G.A., de Broyer, C., de Voogd, N.J., Gordon, D.P., Hoeksema, B.W., Horton, T., Kennedy, M., Mees, J., Poore, G.C.B., Read, G., Stöhr, S., Walter, T.C., Costello, M.J. (eds). (2012). World Register of Marine Species. Accessed at http://www.marinespecies.org on 2012-05-18.

Arntz, W.E., Tarazona, J. (1990). Effects of El Niño 1982-83 on benthos, fish and fisheries off the South American Pacific Coast. Oceanographic Series 52: 323 – 360.

Battaglia, P., Romeo, T., Consoli, P., Scotti, G., Andaloro, F. (2010). Characterisation of the artisanal fishery and its socio-economic aspects in the central Mediterranean Sea (Aelian Islands, Italy). Fisheries Research 102: 87 – 97.

Bell, J.D., Kronen, M., Vunisea, A., Nash, W.J., Keeble, G., Demmke, A., Pontifex, S., Andrèfouët, S. (2009). Planning the use of fish for food security in the Pacific. Marine Policy 33 (1): 64 – 67.

Benfield, M.C., Bosschieter, J.R., Forbes, A.T. (1989). Growth and emigration of *Penaeus indicus* H. Milne-Edwards (Crustacea: Decapoda: Penaeidae) in the St. Lucia Estuary, Southern Africa. Fishery Bulletin 88, 21 – 28.

Berks, F., Mahon, R., McConney, P., Pollnac, R., Pomeroy, R. (2001). Managing small-scale fisheries: alternative directions and methods. IDRC, Ottawa.

Bishop, J.M., Khan, M.H. (1991). Depth as a factor in abundance and size of juvenile penaeid shrimps in the absence of estuaries and marshes. Marine Biology 109: 103-114.

Blaber, S.J.M., Brewer, D.T., Salini, J.P. (1989). Species composition and biomasses of fishes in different habitats of a tropical northern Australian fishery: their occurrence in the adjoining sea and estuarine dependence. Estuarine, Coastal and Shelf Science 29: 509 – 531.

Blaber, S.J.M, Brewer, D.T., Salini, J.P., Kerr, J. (1990). Biomasses, catch rates and abundances of demersal fishes, particularly predators of prawns in a tropical bay in the Gulf of Carpentaria, Australia. Marine Biology 107(3): 397 – 408.

Bouillon, S., Dehairs, F. (2007). Biogeochemistry of the Tana estuary and delta (northern Kenya). Limnology Oceanography 52, 46 – 59.

Bouillon, S., Abril, G., Borges, A.V., Dehairs, F., Govers, G., Hughes, H., Merckx, R., Meysman, F.J.R., Nyunja, J., Osburn, C., Middelburg, J.J. (2009). Distribution, origin and cycling of carbon in the Tana River (Kenya): a dry season basin-scale survey from headwaters to the delta. Biogeosciences Discussion 6, 5959 – 6023.

British Admiralty Chart No. 3362. (1957). Malindi to Ras Chiambone. Region 5 – R5. Scale: 300,000.

Bray, J.R, Curtis, J.T. (1957). An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 27: 325 – 349.

Caddy, J.F. (1999). Fisheries management in the twenty-first century: Will new paradigms apply? Reviews in Fish Biology and Fisheries 9: 1-43.

Castello, L., Viana, J.P., Watkins, G., Pinedo-Vasquez, M., Luzadis, V.A. (2009). Lessons from integrating fishers of Arapaima in small-scale fisheries management at the Mamiraua Reserve, Amazon. Environmental Management 43: 197 – 209.

Chabanet, P., Durvel, P. (2005). Reef fish inventory of Juan de Nova's natural no-take area (Western Indian Ocean). Western Indian Ocean Journal of Marine Science 4: 145 – 162.

Chong, K.C., Dwponngo, A., Ilyas, S., Martosubroto, P. (1987). Some experiences and highlights of the Indonesian trawl ban: bioeconomics and socio-economics. Indo-Pac Fish Comm RAPA rep 10: 458-477.

Chopin, F.S., Arimoto, T. (1995). The condition of fish escaping from fishing gear types: a review. Fisheries Research 21: 315 – 327.

Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Pratchett, M.S., Wilson, S.K., Raina, J.B. (2009). Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. Journal of Applied Ecology 46: 724 – 732.

Clarke, K.R., Warwick, R.M. (2001). *Change in marine communities: an approach to statistical analysis and interpretation*, 2nd edition. PRIMER-E: Plymouth.

Colloca, F., Crespi, V., Cerasi, S., Coppola, S.R. (2004). Structure and evolution of the artisanal fishery in Southern Italian coastal area. Fisheries Research 69: 359 – 369.

Dall, W., Hill, B.J., Rothisberg, P.C., Staples, D.J. (1990). The biology of the Penaeidae. Advanced Marine Biology 27, 1 – 489.

Datoo, B.A. (1974). Influence of monsoons on movement of dhows along the East African coast. East Afric Geog Rev 12: 23-33.

Davies, T.E., Beanjara, N., Tregenza, T. (2009). Socio-economic perspective on gear-based management in an artisanal fishery in south-west Madagascar. Fisheries Management and Ecology 16: 279-289.

de Freitas, A.J. (1986). Selection of nursery areas by six Southeast African Penaeidae. Estuarine Coastal and Shelf Science 23, 901 – 908.

de Freitas, A.J. (2011). The Penaeoidea of South Africa IV- The Family Penaeidae: Genus *Penaeus*. Oceanographic Research Institute Investigational Report No. 59. 125pp.

Demetriades, N.T., Forbes, A.T. (1993). Seasonal changes in the species composition of the penaeid prawn catch on the Tugela Bank, Natal, South Africa. South African Journal of Marine Science 13, 317 – 322.

De Young, C., Charles, A., Hjort, A. (2008). Human dimensions of the ecosystem approach to fisheries: An overview of context, tools and methods. Fisheries technical paper No. 489. FAO, Rome Italy.

Douvere, F. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. Marine Policy 32(5): 762-771.

Ellis, F. (1999). *Rural livelihood diversity in developing countries: Evidence and policy implications*. (Natural Resource Perspective 40). London: Overseas Development Institute.

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries.* Oxford: Oxford University Press.

Eyo, E.A., Solarin, B.B., Isebor, C.E., Williams, A.B. (2005). Assessment of fish bycatch species from coastal artisanal shrimp beam trawl fisheries in Nigeria. Fisheries Research 71: 125-132.

FAO. (2003). The ecosystem approach to fisheries. FAO technical guidelines for responsible fisheries, No. 4, suppliment 2. FAO Fisheries Department. Rome, 112 pp.

FAO. (2005). Putting into pactice the ecosystem approach to fisheris. Rome, FAO. 76 pp.

Farrugio, H., Oliver, P., Biagi, F. (1993). An overview of the history, knowledge, recent and future trends in Mediterranea fisheries. Scientia Marina 57: 105 – 119.

Fennessy, S.T. (1994). Incidental capture of elasmobranchs by commercial prawn trawlers on the Tugela Bank, Natal, South Africa. South African Journal of Marine Science 14: 287 – 296.

Fennessy, S.T., Mwatha, G.K., Thiele, W. (Eds). (2004). Report of the regional workshop on approaches to reducing shrimp trawl by-catch in the Western Indian Ocean. Mombasa, Kenya, 13-15 April 2003. *FAO fisheries report.* No.734. Rome, FAO.49pp.

Fennessy, S.T., Vincent, X., Budeba, Y., Mueni, E., Gove, D.Z. (2008). An update on initiatives to reduce prawn trawl by-catch in the Western Indian Ocean. Western Indian Ocean Journal of Marine Science 7(2): 217 – 222.

Fischer, W., Bianchi, G. (1984). *FAO species identification sheets for fishery purposes. Western Indian Ocean Fishing Area* 51. Vol. V.

Fisheries Department, Moi University. (2006). Status and impact of the prawn fishery in Malindi-Ungwana Bay: Implications for management and conservation. Ministry of Livestock and Fisheries Development. Unpublished technical report. 45 pp.

Friedlander, A.M., DeMartini, E.E. (2002). Contrasts in density, size and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. Marine Ecological Progress Series 230: 253 – 264.

Froese, R., Binohlan, C. (2000). Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes with a simple method to evaluate length-frequency data. Journal of Fish Biology, 56: 758 – 773.

Froese, R., Pauly, D. (Eds). (2012). FishBase. World Wide Web electronic publication. www.fishbase.org, version (04/2012).

Forbes, A.T., Demetriades, N.T. (2005). A review of the commercial, shallow water penaeid prawn resource of South Africa: Status, fisheries, aquaculture and management. Specialist report prepared for Ezemvelo KZN Wildlife, South Africa. Marine and Estuarine Research. 64 pp.

Forbes, A.T., Benfield, M.C. (1986a.) Penaeid prawns in the St. Lucia Lake system: Post-larval recruitment and the bait fishery. South African Journal of Zoology 21, 224 – 228.

Forbes, A.T., Benfield, M.C. (1986b). Tidal behaviour of post-larval penaeid prawns (Crustacea: Decapoda: Penaeidae) in a Southeast African estuary. Journal of Experimental Marine Biology 102, 23 – 34.

Fulanda, B. (2003). Shrimp trawling in Ungwana Bay: A threat to fishery resources. In: Hoorweg J, Muthiga N (eds.). Recent advances in coastal ecology: Studies from Kenya. PrintPartners Ipskamp Bv, Enschede, 233 – 42.

Fulanda, B., Munga, C.N, Ohtomi, J., Osore, M., Mugo, R., Md. Hossain, Y. (2009). The structure and evolution of the coastal migrant fishery of Kenya. Ocean & Coastal Management 52: 459-466.

Fulanda, B., Ohtomi, J., Mueni, E., Kimani, E. (2011). Fishery trends, resource-use and management system in the Ungwana Bay fishery, Kenya. Ocean & Coast Management 54: 401-414.

Garcia, S.M., Cochrane, K.L. (2005). Ecosystem approach to fisheries: a review of implementation guideline[1]. ICES Journal of Marine Science 62: 311 – 318.

Garcia, S., le Reste, L. (1981). Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. FAO Fisheries Technical Paper, 203. Rome. 215 pp.

Garcia, A.M., Vieira, J.P., Winemiller, K.O. (2003). Effects of 1997 – 1998 El Niño on the dynamics of the shallow-water fish assemblage of the Patos Lagoon Estuary (Brazil). Estuarine Coastal and Shelf Science 57(3): 489 – 500.

Gillet, R. (2008). Global study of shrimp fisheries. FAO document technique sur le peches. No. 475. Rome, FAO. 331 pp.

Glaesel, H. (1997). *Fishers, parks, and power: The socio-environmental dimensions of marine resource decline and protection on the Kenya coast.* (Ph.D. Thesis). Madison: University of Wisconsin.

Gobert, B. (1994). Size structures of demersal catches in multispecies multigear tropical fishery. Fisheries Research 19: 87 – 104.

Government of Kenya (1991). Fisheries Act Cap 378 – Laws of Kenya. Government Press, Nairobi.

Government of Kenya. (2001). Gazette notice No. 7565 of 31/10/2001.

Government of Kenya. (2002). Kenya 1999 population and housing census. Central Bureau of Statistics, Ministry of Finance and Planning. Nairobi, Kenya.

Government of Kenya. (2008a). Kenya state of the coast report: towards the integrated management of Kenya's coastal and marine resources. UNEP and NEMA, Nairobi.90pp.

Government of Kenya. (2008b). Marine waters fisheries frame survey 2008 report. Ministry of Fisheries Development, Department of Fisheries, Nairobi. 62 pp.

Government of Kenya. (2009). Kenya Territorial Sea/Exclusive Economic Zone. Survey of Kenya.

Government of Kenya. (2010a). Fisheries annual statistical bulletin 2010. Ministry of Fisheries Development, Department of Fisheries, Nairobi. 56 pp.

Government of Kenya. (2010b). The prawn fishery management plan 2010. Kenya gazette supplement No.13. Legal notice No. 20. 8 pp.

Government of Kenya. (2012). Marine waters fisheries frame survey 2012 report. Ministry of Fisheries Development, Department of Fisheries, Nairobi. 85 pp.

Gribblea, N.A., Wassenberg, T.J., Burridge, C. (2007). Factors affecting the distribution of commercially exploited penaeid prawns (shrimp) (Decapod: Penaeidae) across the northern Great Barrier Reef, Australia. Fisheries Research 85: 174-185

Hall, M.A. (1996). On by-catches. Reviews in Fish Biology and Fisheries 6: 134 – 155.

Hall, M.A., Alverson, D.L., Metuzal, K.I. (2000). By-catch; problems and solutions; seas at millennium: an environmental evaluation. In: Sheppard CR (ed.). Global Issues and Processes 3: 135-151.

Halliday, R.G., Pinhorn, A.T. (2002). A review of the scientific and technical bases for policies on the capture of small fish in North Atlantic groundfish fisheries. Fisheries Research 57: 211-222.

Hardin, G. (1968). The tragedy of the commons. Science 162: 1243-1248.

Hicks, C.C., McClanahan, T.R. (2012). Assessing gear modifications needed to optimise yields in a heavily exploited, multispecies, sea grass and coral reef fishery. PloS ONE 7(5): e36022. Doi: 10.1371/journal.pone.0036022.

Hill, B.J. (1975) Abundance, breeding and growth of the crab *Scylla serrata* in two South African estuaries. Marine Biology 32:119-126.

Holthuis, L.B. (1980). FAO species catalogue.Vol. 1.Shrimps and prawns of the world. FAO Fisheries Synopsis No. 125, 1 – 271.

Hoorweg, J., Versleijen, N., Wangila, B., Degen, A. (2006). Income diversification and fishing practices among artisanal fishers on the Malindi-Kilifi coast. In: Hoorweg, J., Muthiga, N. (eds.). Advances in coastal ecology: People, processes and ecosystems in Kenya. PrintPartners Ipskamp Bv, Enschede 20: 41-59.

Hudson, A.V., Furness, R.W. (1988). Utilisation of discarded fish by scavenging seabirds behind white fish trawlers in Shetland. Journal of Zoology (London) 215: 151 – 166.

Hughes, D.A. (1966). Investigations of the "nursery areas" and habitat preferences of juvenile penaeid prawns in Mozambique. Journal of Applied Ecology 3, 349- 354.

Iversen, S.A. (1984). Kenyan marine fish resources in waters deeper than 10 meters investigated by R/V "DR. FRIDTJOF NANSEN". In: Iversen, S.A., Myklevoll, S. (eds.). Proceedings of the NORAD-Kenya seminar to review the marine fish stocks and fisheries in Kenya, 13-15 March 1984, Mombasa, Kenya.

Jennings, S., Kaiser, M.J. (1998). The effects of fishing on marine ecosystems. Advanced Marine Biology 34: 201-351.

Johannes, R.E. Freeman, M.R., Hamilton, R.J. 2000. Ignore fishers' knowledge and miss the boat. Fish and Fisheries 1: 257 – 271.

Jones, J.B. (1992). Environmental impact of trawling on the seabed: A review, New Zealand Journal of Marine Freshwater Research 26: 59-67.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R. (2002). Modifications of marine habitats by trawling activities: prognosis and solution. Fish and Fisheries. 3: 114 – 136.

Kaiser, M.J., Spencer, B.E. (1996). The effects of beam trawl disturbance on faunal communities in different habitats. Journal of Animal Ecology 65: 48-358.

Kaiser, M.J., Hill, A.S., Ramsay, K., Spencer, B.E., Brand, A.R., Veal, L.O., Prudden, K., Rees, E.I.S., Munday, B.W., Ball, B., Hawkins, S.J. (1997). An estimate of fishing gear disturbance intensities in the Irish Sea: a comparison of beam trawling and scallop dredging. Aquatic Conservation 6: 269-285.

Kaunda-Arara, B., Rose, G.A., Muchiri, M.S. and Kaka, R. (2003). Long term trends in coral reef fish yields and exploitation rates of commercial species from coastal Kenya. Western Indian Ocean J. Mar. Sci. 2(2): 105-116.

Kelleher, K. (2005). Discards in the world's marine fisheries. An update. FAO Fisheries Technical Paper. No. 470. Rome: FAO. 131 pp.

Kenya Bureau of Statistics. (2012). Kenya facts and figures. 83 pp.

Kenya Marine and Fisheries Research Institute (KMFRI). (2002). Current status of trawl fishery of Malindi-Ungwana Bay. Unpublished technical report. 97 pp.

Kimani, E., Manyala, J., Aura, C., Ndoro, C. (2010). Malindi-Ungwana Bay environment and prawn fisheries survey. Kenya Coastal Development Project, unpublished technical report. 66 pp.

Kimani, E., Manyala, J., Munga, C.N., Ndoro, C. (2011). Malindi-Ungwana Bay shallow water prawn survey SWIOFP Component 2. SWIOFP2011201a. Unpublished technical report. 91 pp.

Kimani, E., Munga, C.N., Ndoro, C., Manyala, J., Thoya, P., Amisi, J. (2012). Malindi-Ungwana Bay shallow water prawn survey SWIOFP Component 2. SWIOFP2011C201b. Unpublished technical report. 49 pp.

Kimani, E., Munga, C.N., Thoya, P., Anam, R., Ruwa, R., Ong'anda, H., Ndoro, C. (2013). Deep water crustacean trawl survey SWIOFP Component 2. Voyage KEN2011C203. SWIOFP survey technical report. 44 pp.

King, M.G. (1995). *Fisheries biology, assessment and management. Fishing news books*. Osney Mead, Oxford, England.341 pp.

Kitheka, J.U., Obiero, M., Nthenge, P. (2005). River discharge, sediment transport and exchange in the Tana estuary, Kenya. Estuarine and Coastal Shelf Science 63:455-468.

Kitheka, J.U. (2013). River sediment supply, sedimentation and transport of the highly turbid sediment plume in Malindi Bay, Kenya. Journal of Geographical Science 23(3): 465 – 489.

Kolding, J., Zwieten P.A.M. (2011). The tragedy of our legacy: How do global management discourses affect small scale fisheries in the south?, Forum for Development Studies, 38(3): 267-297.

Kronen, M. (2004). Fishing for opportunities? A socio-economic assessment of Tonga's artisanal fisheries. Fisheries Research 70: 121 – 134.

Kronen, M., Vunisea, A., Magron, F., McArdle, B. (2010). Socio-economic drivers and indicators for artisanal coastal fisheries in Pacific island countries and territories and their use for fisheries management strategies. Marine Policy 34: 1135 – 1143.

Kronen, M., Pinca, S., Magron, F., McArdle, B., Vunisea, A., Vigliola, L., Kulbicki, M., Andrefouet, S. (2012). Socio-economic and fishery indicators to identify and monitor artisanal finfishing pressure in Pacific Island countries and territories. Ocean & Coastal Management 55: 63 – 73.

Kulmiye, A.J., Mavuti, K.M. (2004). Growth and moulting of captive *Panulirus homarus homarus* in Kenya, Western Indian Ocean. *Paper presented at the 7th International Conference on lobster biology and management*, 8th – 13th February 2004, Hotel Grand Chancellor, Hobart, Tasmania, Australia. 25 pp.

Kuster, C., Vuki, V., Zann, L. (2006). Validation of the accuracy of household reporting of subsistence fishing catch and effort: a Fijian case study. Fisheries Management and Ecology 13: 177 – 184.

le Monach, F., Gough, C., Humber, F., Harper, S., Zeller, D. (2011). Reconstruction of total marine fisheries catches for Madagascar (1950 – 2008). Fisheries Centre Reports, Vol. 19 No. 4.143 pp.

Lieske, E., Myers, R. (1994). *Collins pocket guide to coral reef fishes:* Indo-pacific and Caribbean. Herper Collins Publisher, London. 400 pp.

Loneragan, N.R., Bunn, S.E. (1999). River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. Australian Journal of Ecology 24: 431 – 440.

Macia, A. (2004). Juvenile penaeid shrimp density, spatial distribution and size composition in four adjacent habitats within a mangrove-fringed bay on Inhaca Island, Mozambique. Western Indian Ocean Journal of Marine Science 3: 163-78.

Mangi, S.C., Roberts, C.M., Rodwell, L.D. (2007). Reef fisheries management in Kenya: Preliminary approach using the driver-pressure-state-impacts-response (DPSIR) scheme of indicators. Ocean & Coastal Management 50: 463 – 480.

Mangi, S.C., Roberts, C.M. (2006). Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. Marine Pollution Bulletin 52: 1646 – 1660.

Mathew, S. (2001). Small-scale fisheries perspectives on an ecosystem-based approach to fisheries management. *Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem*. Reykjavik, Iceland: FAO, 18 pp.

McClanahan, T.R. (1988). Seasonality in East Africa's coastal waters. Marine Ecology Progress Series 44: 191-199.

McClanahan, T.R., Kaunda-Arara, B. (1996). Fish recovery in a coral reef marine no-take area and its effect on adjacent fishery. Conservation Biology 10: 1187 – 1199.

McClanahan, T.R., Young, T.P. (1996). *East African ecosystems and their conservation*. New York: Oxford University Press. 100 pp.

McClanahan, T.R., Glaesel, H., Rubens, J., Kiambo, R. (1997). The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystem of Southern Kenya. Environmental Conservation 24: 105-120.

McClanahan, T.R., Maina, J., Pet-Soede, L. (2002). Effects of the 1998 coral mortality event on Kenyan coral reefs and fisheries. Ambio 31: 7-8.

McClanahan, T.R., Mangi, S.C. (2004). Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. Fisheries Management and Ecology 11: 51 – 60.

McClanahan, T.R., Mwaguni, S., Muthiga, N.A. (2005). Management of the Kenyan coast. Ocean & Coastal Management 48: 901-931.

McClanahan, T.R., Cinner, J.E. (2008). A framework for adaptive gear and ecosystem-based management in the artisanal coral reef fishery of Papua New Guinea. Aquatic Conservation: Marine and Freshwater Ecosystems 18: 493 – 507.

MacLennan, D.N. (1992). Fishing gear selectivity: an overview. Fisheries Research 13: 201 – 204.

MacLennan, D.N. (1995). Gear selectivity and variation of yield. ICES Journal of Marine Science 52: 827 – 836.

Martin, B. E. (1973). *The History of Malindi. A Geographical Analysis of an East African Coastal Town from the Portuguese Period to Present.* East African Literature Bureau. 301pp.

Marquez-Farias, J.F. (2005). Gillnet mesh selectivity for the shovelnose guitarfish (*Rhinobatus productus*) from fishery-dependent data in the artisanal ray fishery of the Gulf of Carlifornia, Mexico. Journal of North West Atlantic Fisheries Science 35: 443 – 452.

Matic-Skoko, S., Staglicic, N., Pallaoro, A., Kraljevic, M., Dulcic, J., Tutman, P., Dragicevic, B. (2011). Effectiveness of conventional management in Mediterranean type artisanal fisheries. Estuarine, Coastal and Shelf Science 91: 314 – 324.

Mbuga, J. S. (1984). Fishing gears of the Kenya marine waters. In: S. A. Iversen and S. Myklevoll (Eds). The proceedings of the Norad-Kenya seminar to review the marine fish stocks and fisheries in Kenya Mombasa, Kenya, 13–15 March 1984.

Meltzer, L., Blinick, N.S., Fleishman, A.B. (2012). Management implications of the biodiversity and socio-economic impacts of shrimp trawl by-catch in Bahia de Kino, Sonara, Mexico. PLoS ONE 7(6): e35609.doi:10.1371/journal.pone.0035609.

Middleton, J. (2000). The peoples. In: Hoorweg, J., Foeken, D., Obudho, R. (Eds.). *Kenya Coast Handbook: Culture, resources and development in the East African littoral.* 101 – 114 pp.

Mkare, T.K. (2013). Genetic population structure of penaeid prawns *Penaeus monodon* Fabricius 1798, *Fenneropenaeus indicus* H. Milne Edwards 1837 and *Metapenaeus monoceros* Fabricius 1798 in the Malindi–Ungwana Bay, Kenya. MSc Thesis. University of Stellenbosch, South Africa.

Mueni, E., Mwangi, J. (2001). A survey on the use of Turtle Excluder Devices (TEDs) in trawlers along the Kenyan coast. KWS Series-KESCOM Tech Rep 1.

Munga, C.N., Mohamed, M.O.S., Obura, D.O., Vanreusel, A., Dahdouh-Guebas, F. (2010). Resource users' perceptions on continued existence of the Mombasa Marine Park and Reserve, Kenya. Western Indian Ocean Journal of Marine Science 9(2): 213 – 225.

Munga, C.N, Ndegwa S., Fulanda B., Manyala J., Kimani E., Ohtomi J. and Vanreusel A. (2012a). Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fisheries Science* 78: 209-219.

Munga, C.N., Mohamed, M.O.S, Nassir, A., Dahdouh-Guebas, F., Obura, D.O., Vanreusel, A. (2012b). Status of coral reef fish communities within the Mombasa marine protected area, Kenya, more than a decade after establishment. Western Indian Ocean Journal of Marine Science 10(2): 169 – 184.

Munga, C.N., Mwangi, S., Ong'anda, H., Ruwa, R., Manyala, J., Groeneveld, J.C., Kimani, E. and Vanreusel, A. (2013). Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys. Fisheries Research 147: 93 – 102.

Munro, J.L., Gaut, V.C., Thompson, R. (1973). Spawning seasons of Caribbean reef fishes. Journal of Fish Biology 5: 69 – 84.

Mutagyera, W.B. (1984). Distribution of some deep water prawn and lobster species in Kenya's waters. *In:* Iversen, S.A. and Myklevoll, S. (eds). *The proceedings of the NORAD-Kenya seminar to review the marine fish stocks and fisheries in Kenya*, Mombasa, Kenya, 13 – 15 March 1984.

Mwatha, G.K. (2002). Assessment of the prawn fishery, by-catch, resource use conflicts and performance of the turtle excluder device. *In:* KMFRI. Current status of trawl fishery of Malindi-Ungwana Bay. Unpublished technical report. 97 pp.

Mwatha, G.K. (2005). Stock assessment and population dynamics of penaeid prawns in the prawn trawling grounds of Malindi-Ungwana Bay: The challenges of managing the prawn fishery in Kenya. WIOMSA/MARG-I/2005-06. 21 pp.

Niamaimandi, N., Aziz, A., Khalijah, D.S., Roos, S., Kiabi, B. (2008). Reproductive biology of the green tiger prawn (*Penaeus semisulcatus*) in coastal waters of Bushehr, Persian Gulf. ICES Journal of Marine Science. Doi: 10.1093/icesjms/fsn 172.

Nichols, S. (1990). The by-catch issue. In: The Mississippi shrimp industry. A management perspective. *Proceedings of a Mississippi Sea Grant Advisory Service Workshop, Biloxi, Mississippi,* April 1989. Remy, K.H. (Ed.). Biloxi, Mississippi; Mississippi State University: 40 – 45.

Nzioka, R.M. (1979). Observations on the spawning seasons of East African reef fishes. Journal of Fish Biology 14: 329-342.

Ochiewo, J. (2004). Changing fisheries practices and their socio-economic implications in south coast Kenya. Ocean & Coastal Management 47: 389-408.

Ochiewo, J., Torre-Castro, M., Muthama, C., Munyi, F., Nthuta, J.M. (2010). Socio-economic features of sea cucumber fisheries in southern coast of Kenya. Ocean & Coastal Management 53: 192 – 202.

Olbers, J.M., Fennessy, S.T. (2007). A restrospective assessment of the stock status of Otolithes ruber (Pisces: Sciaenidae) as by-catch on prawn trawlers from KwaZulu-Natal, South Africa. African Journal of Marine Science 29(2): 247 – 252.

Pallant, J. (2001). *SPSS survival manual: A step by step guide to data analysis using SPSS for windows* (versions 10 and 11). ISBN: 0335223664. 352 pp.

Parsons, T.R.; Maita, Y., Lalli, C.M. (1984). *A manual of chemical and biological methods for seawater analysis.* Pergamon press. 173 pp.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. Journal du Conseil international pour l'Exploration de la Mer 39, 175-192.

Pauly, D., Murphy, G.I. (1982). Theory and management of tropical fisheries. *ICLARM Conference Proceedinngs International Centre for Living Aquatic Resource Management (ICLARM) and Centre for Scientific and Industrial Research Organization (CSIRO).* Ronulla, Australia. 360 pp.

Pauly, D., Palomares, M.L., Froese, R., Vakily, P.S.M., Preikshot, D., Wallace, S. (2001). Fishing down Canadian aquatic food webs. Canadian Journal of Fish and Aquatic Sciences 58: 51 – 62.

Pomeroy, R.S., Rivera-Guieb, R. (2006). *Fishery Co-management:* A practical handbook. Oxford University Press, Oxford. 288 pp.

Pontecorvo, G., Schrank, W.F. (2001). A small core fishery: a new approach to fisheries management. Marine Policy 25: 43 – 48.

Rabago-Quiroz, C.H., Lopez-Martinez, J., Herrera-Valdivia, E., Navare-Martinez, M.O., Rodriguez-Romero, J. (2008). Population dynamics and spatial distribution of flatfish species in shrimp trawl bycatch in the Gulf of California. Hidrobiologica 18 (3): 177 – 188.

Roberts, C.M., Polunin, N.V.C. (1993). Marine reserves: Simple solutions to managing complex fisheries? Ambio 22: 363-368.

Teh, L.C.L., Teh, L.S.L., Starkhouse, B., Sumaila, U.R. (2009). An overview of socio-economic and ecological perspectives of Fiji's inshore reef fisheries. Marine Policy 33: 807 – 817.

Teikwa, E.D., Mgaya, Y.D. (2003). Abundance and reproductive biology of the Penaeid prawns of Bagamoyo coastal waters, Tanzania. Western Indian Ocean Journal of Marine Science 2, 117 – 126.

Tonks, M.L., Griffiths, S.P., Heales, D.S., Brewer, D.T., Dell, Q. (2008). Species composition and temporal variation of prawn trawl bycatch in the Joseph Bonaparte Gulf, northwesten Australia. Fisheries Research 89, 276-293.

Tremain, D.M., Adams, D.H. (1995). Seasonal variations in species diversity, abundance and composition of fish communities in the northern Indian River Lagoon, Florida. Bulletin of Marine Sciences 57: 171 – 192.

Turner, R., Cakacaka, A., Graham, N., Polunin, N., Pratchett, M., Stead, S. (2007). Declining resilience on marine resources in remote south Pacific societies: ecological versus socio-economic drivers. Coral Reefs 26: 997 – 1008.

Tychsen, J. (ed.). (2006). KenSea. *Environmental sensitivity atlas for coastal areas of Kenya*, 76 pp. Copenhagen; Geological Survey of Denmark and Greenland (GEUS); ISBN 87-7871-191-6.

Saetersdal, G., Bianchi, G., Stromme, T., Venema, C. (1993). The Dr. Fridtjof Nansen Programme 1975–1993. Investigations of fishery resources in developing countries.

History of the programme and review of results. FAO Fisheries Technical Paper No. 391. Rome, FAO. 434 pp.

Salas, S., Chuenpagdee, R., Seijo, J.C., Charles, A. (2007). Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. Fisheries Research 87: 5 – 16.

Semesi, A.K., Mgaya, Y.D., Muruke, M.H.S, Francis, J., Mtolera, M., Msumi, G. (1998). Coastal resources utilisation and conservation issues in Bagamoyo. Ambio 27, 635 – 644.

Smith, T.D. (1994). *Scaling fisheries. The science of measuring the effects of fishing*, Cambridge: Cambridge University Press. Pp 1855-1955.

Smith, J.L.B., Heemstra, R. (1998). *Smith's sea fishes,* fourth ed. Valiant publishing santom, South Africa. 578 pp.

Somers, I.F. (1987). Sediment type as a factor in the distribution of prawn species in the Western Gulf of Carpentaria. Australian Journal of Marine Freshwater Research 38: 133-49.

Somers, I.F. (1994). Species composition and distribution of commercial penaeid prawn catches in the Gulf of Carpentaria, Australia, in relation to depth and sediment type. Australian Journal of Marine Freshwater Research 45: 317-335.

Soykan, C.U., Moore, J.E., Zydelis, R., Crowder, L.B., Safina, C., Lewison, R.L. (2008). Why study by-catch? An introduction to the theme section on fisheries by-catch. Endangered Species Research 5: 91 – 102.

Sparre, P., Ursin, E., Venema, S.C. (1989). Introduction to tropical fish stock assessment: Part 1 manual. FAO fisheries technical paper 306/1.

Staglicic, N., Matic-Skoko, A., Pallaoro, R., Grgicevic, M., Kraljevic, P., Tutman, B., Dulcic, D.J. (2011). Long-term trends in the structure of eastern Adriatic littoral fish assemblages: Consequences for fisheries management. Estuarine, Coastal and Shelf Science 94: 263 – 271.

Stearns, P.N. (Ed.)., 2001. *The encyclopedia of world history: Ancient, medieval, and modern.* Houghton Mifflin company, New York.

Stergiou, K.I., Erzini, K. (2002). Comparative fixed gear studies in the Cyclades (Aegian Sea): Size selectivity of small-hook longlines and monofilament gill nets. Fisheries Research 58: 25 – 40.

Stobutzki, I., Miller, M., Brewer, D. (2001). Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch. Environmental Conservation 28, 167-181.

Schwing, F.B., Palacios, D.M., Bograd, S.J. (2003). El Niño impacts of the California current ecosystem. NOAA Fisheries, SWFSC, CA.

Schwing, F.B., Murphree, T., de Witt, L., Green, P.M. (2002). The evolution of oceanic and atmospheric anomalies in the Northeast Pacific during the El Niño and La Niña events of 1995 – 2000. Progressive Oceanography 54: 459 – 491.

Tonks, M.L., Griffiths, S.P., Heales, D.S., Brewer, D.T., Dell, Q. (2008). Species composition and temporal variation of prawn trawl by-catch in the Joseph Bonaparte Gulf, northwesten Australia. Fisheries Research 89, 276-293.

van der Elst, R.P., Everret, B.I., Jiddawi, N., Mwatha, G., Alfonso, P.S., Boulle, D. (2005). Fish, fishers and fisheries of the Western Indian Ocean; their diversity and status, a preliminary assessment. Philosophical Transactions of the Royal Society of London A 363: 263 – 284.

van der Elst, R.P. (1981). *A guide to the common sea fishes of Southern African*. Struik fisher Publishers, Cape Town 8001, South Africa. 398 pp.

van Oostenbrugge, J.A.E., Bakker, E.J., van Densen, W.L.T, Michiels, M.A.M, van Zwieten, P.A.M. (2002). Characterising catch variability in a multispecies fishery: implications for fishery management. Canadian Journal of Fisheries and Aquuatic Science 59: 1032 – 1043.

Vance, D.J., Heales, D.S., Loneragan, N.R. (1994). Seasonal, diel and tidal variation in beam-trawl catches of juvenile grooved tiger prawns, *Penaeus semisulcatus* (Decapoda: Penaeidae), in the Embley River, north-eastern Gulf of Carpentaria, Australia. Australian Journal of Marine and Freshwater Research 45, 35-42.

Venema, S.C. (1984). Review of marine resource surveys in Kenyan waters. In: Iversen, S.A., Myklevoll, S. (eds.). *Proceedings of the NORAD-Kenya seminar to review the marine fish stocks and fisheries in Kenya,* 13- 15 March 1984, Mombasa, Kenya.

Wassenberg, T.J., Hill, B.J. (1989). The effect of trawling and subsequent handling on the survival of the by-catch of prawn trawlers in Moreton Bay, Australia. Fisheries Research 7: 99 – 110.

WWF. (2004). Eastern African Marine Ecoregion. Towards a western Indian Ocean dugong conservation strategy: The status of dugongs in the western Indian Ocean region and priority conservation actions. Dar es Salaam, Tanzania, WWF. 68 pp.

Zar, J.H. (1999). *Biostatistical analysis*. Fourth Edition. Prentice-Hall, New Jersey. 663 pp. (main text) + 212 pp (appendices).

Appendices

The Malindi-Ungwana Bay artisanal fishers socio-economic survey

The aim of this survey is to assess the contribution of fishing activity as a livelihood to the fisher households within the Malindi-Ungwana Bay. This questionnaire also investigates the perceptions of the artisanal fishers on the shrimp trawling and management in the area.

Name of data Collector: ______________________________Date:____/____/2012

Location ____________________________

1. Personal Information

a) Name of Fisher ______________________________ Place of Birth____________________
   Residence ______________________________________

b) Age (yrs):- __________ Size of household _____________ Education level (Tick where applicable): No education (1), Incomplete primary (2) , Complete primary (3) , Incomplete secondary (4) Completed Secondary (5), Higher education (6), Madrassa (7), Other (please specify) (8)

   ____

c) No. of spouses. ________No. of children < 18 yrs ______ ≥ 18 yrs _________

d) Why are you a fisherman? ____

2. Fishing Operations

a) Common fishing grounds: NEM ___________________ SEM_________________

b) Which fishing gear do you use? ____

c) Gear ownership (tick one): (Self), (Shared), (Hired), mployer's), (Other)____

d) Fishing craft type used? ____

e) Craft ownership (tick one): (Self), (Shared), (Hired), (Employer's), (Other)______

f) Days fished during the last one Week (tick one):- (1), (2), (3), (4), (5), (6), (7)

g) Number of days normally fished in a week: NEM:__________SEM:_____________

h) How much have you landed today ___________ Kg

i) Amount of fish for home consumption today? ________________ Kg

j) Amount of fish sold today and by grade?

Grade 1	__________________ Kg	Kshs	_____________________
Grade 2	__________________ Kg	Kshs	_____________________
Grade 3	__________________ Kg	Kshs	_____________________

k) Target fish species:

NEM: _________________ SEM: _____________________

3. Alternative livelihoods

a) Any other sources of income (occupations) for the household and average monthly income? (indicate who is involved in the household)

1:_____________________________________ Kshs_____________________

2:_____________________________________ Kshs_____________________

3:_____________________________________ Kshs_____________________

4:_____________________________________ Kshs_____________________

b) Rank the income sources in order of their contribution to the household income beginning with fishing on a scale of 1 - 3 (1 extremely important; 2 very important; 3 important)

1: _______________________________ Rank _____

2: _______________________________ Rank _____

3: _______________________________ Rank _____

4: _______________________________ Rank _____

5: _______________________________ Rank _____

4. Shrimp trawling activity

a) Have you experienced any conflict with the shrimp trawling activity? Yes ____ No ____

b) If yes, indicate what kind of conflict you have experienced:

____

c) Should shrimp trawling be allowed to continue? Yes _______ No _______

d) If yes, give your reasons:

____

____

e) If no, give your reasons:

____

____

f) If you were given an opportunity to work in a trawler (as a crew), would you accept it?

Yes ________________ No ____________________

g) If the answer is yes, give reasons

____

____

h) What are your views on the prawn fishery management plan/How would like the prawn fishery to be managed?

____

____

Artisanal finfish species sampled in the Malindi-Ungwana Bay

Species	Family	Number sampled (N)	Relative abundance (%)
Pellona ditchela	Clupeidae	337	7.89
Otolithes ruber	Sciaenidae	264	6.18
Lutjanus fulviflamma	Lutjanidae	260	6.09
Siganus sutor	Siganidae	193	4.52
Lobotes surinamensis	Lobotidae	187	4.38
Galeichthys feliceps	Ariidae	183	4.29
Psettodes erumei	Psettodidae	170	3.98
Thryssa vitrirostris	Engraulidae	163	3.82
Gerres oyena	Gerreidae	156	3.65
Leptoscarus vaigiensis	Scaridae	141	3.30
Sphyrna zygaena	Sphyrnidae	127	2.97
Leiognathus equulus	Leiognathidae	127	2.97
Hilsa kelee	Clupeidae	118	2.76
Johnius amblycephalus	Sciaenidae	98	2.30
Carcharhinus melanopterus	Carcharhinidae	86	2.01
Carangoides armatus	Carangidae	86	2.01
Caranx ignobilis	Carangidae	80	1.87
Lethrinus lentjan	Lethrinidae	65	1.52
Terapon jarbua	Terapontidae	63	1.48
Pomadasys maculatus	Haemulidae	59	1.38
Leiognathus daura	Leiognathidae	59	1.38
Hemiramphus far	Hemiramphidae	58	1.36
Scomberoides tol	Scombridae	56	1.31
Scomberoides commersonnianus	Scombridae	51	1.19
Gerres filamentosus	Gerreidae	48	1.12
Johnius dussumieri	Sciaenidae	39	0.91
Tylosurus acus	Trichiuridae	39	0.91
Lethrinus harak	Lethrinidae	36	0.84
Trichiurus lepturus	Trichiuri	36	0.84
Drepane punctata	Drepanidae	32	0.75
Sphyrna lewini	Sphyrnidae	32	0.75
Photopectoralis bindus	Leiognathidae	30	0.70
Thryssa malabarica	Engraulidae	30	0.70
Valamugil seheli	Mugilidae	30	0.70
Dentex marocannus	Sparidae	28	0.66
Lethrinus nebulosus	Lethrinidae	22	0.52
Acanthurus xanthopterus	Acanthuridae	21	0.49
Sillago sihama	Sillaginidae	21	0.49
Siganus canaliculatus	Siganidae	20	0.47
Plotosus lineatus	Plotosidae	20	0.47
Lutjanus argentimaculatus	Lutjanidae	19	0.45

Lethrinus microdon	Lethrinidae	18	0.42
Epinephelus malabaricus	Serranidae	16	0.37
Caranx sexfasciatus	Carangidae	16	0.37
Polydactylus plebeius	Polynemidae	16	0.37
Upeneus vittatus	Mullidae	16	0.37
Chirocentrus dorab	Chirocentridae	15	0.35
Rastrelliger kanagurta	Scombridae	15	0.35
Elops saurus	Elopidae	14	0.33
Lutjanus sanguineus	Lutjanidae	13	0.30
Pelates quadrilineatus	Terapontidae	12	0.28
Thunnus tonggol	Scombridae	11	0.26
Sphyraena putnamae	Sphyraenidae	11	0.26
Upeneus sulphureus	Mullidae	11	0.26
Pomadasys commersonnii	Haemulidae	10	0.23
Netuma thalassina	Ariidae	10	0.23
Mugil cephalus	Mugilidae	10	0.23
Bothus mancus	Bothidae	9	0.21
Trachinotus blochii	Carangidae	9	0.21
Epinephelus tauvina	Serranidae	9	0.21
Plectorhinchus gaterinus	Haemulidae	9	0.21
Mulloidichthys vanicolensis	Mullidae	9	0.21
Carangoides oblongus	Carangidae	9	0.21
Saurida undosquamis	Synodontidae	8	0.19
Euthynnus affinis	Scombridae	8	0.19
Gnathanodon speciosus	Carangidae	7	0.16
Caranx heberi	Carangidae	7	0.16
Plectorhinchus pictus	Haemulidae	7	0.16
Drepane longimana	Drepanidae	7	0.16
Pempheris oualensis	Pempheridae	7	0.16
Albula vulpes	Albulidae	6	0.14
Himantura uarnak	Dasyatidae	6	0.14
Muraenesox cinereus	Muraenesocidae	6	0.14
Triaenodon obesus	Carcharhinidae	6	0.14
Monotaxis grandoculis	Lethrinidae	6	0.14
Hypoatherina temminckii	Atherinidae	6	0.14
Monodactylus argenteus	Monodactylidae	6	0.14
Chanos chanos	Chanidae	6	0.14
Coryphaena hippurus	Coryphaenidae	5	0.12
Chlorurus sordidus	Scaridae	5	0.12
Plectorhinchus schotaf	Haemulidae	5	0.12
Tylosurus crocodilus	Belonidae	5	0.12
Secutor insidiator	Leiognathidae	5	0.12
Plectorhinchus playfairi	Haemulidae	5	0.12
Conger cinereus	Congridae	4	0.09

Carcharhinus sp.	Carcharhinidae	4	0.09
Carcharhinus ablimarginatus	Carcharhinidae	4	0.09
Thunnus albacares	Scombridae	4	0.09
Gymnothorax elegans	Muraenidae	4	0.09
Lethrinus miniatus	Lethrinidae	4	0.09
Paraplagusia bilineata	Cynoglossidae	4	0.09
Monodactylus falciformis	Monodactylidae	4	0.09
Sphyraena jello	Sphyraenidae	4	0.09
Lutjanus kasmira	Lutjanidae	4	0.09
Leiognathus lineolatus	Leiognathidae	4	0.09
Raja miraletus	Rajidae	3	0.07
Rhizoprionodon acutus	Carcharhinidae	3	0.07
Sphyrna sp.	Sphyrnidae	3	0.07
Lichia amia	Carangidae	3	0.07
Muraenichthys schultzei	Ophichthidae	3	0.07
Platax orbicularis	Ephippidae	3	0.07
Aprion virescens	Lutjanidae	3	0.07
Macolor niger	Lutjanidae	3	0.07
Epinephelus coioides	Serranidae	3	0.07
Caranx melampygus	Carangidae	3	0.07
Lutjanus gibbus	Lutjanidae	3	0.07
Pomadasys sp.	Haemulidae	3	0.07
Scomberomorus plurilineatus	Scombridae	3	0.07
Umbrina ronchus	Sciaenidae	3	0.07
Thysanophrys chiltonae	Platycephalidae	3	0.07
Arius africanus	Ariidae	3	0.07
Carangoides ferdau	Carangidae	3	0.07
Alectis indica	Carangidae	3	0.07
Platycephalus indicus	Platycephalidae	3	0.07
Liza macrolepis/Chelon macrolepis	Mugilidae	3	0.07
Sphyraena barracuda	Sphyraenidae	2	0.05
Sphyrna mokarran	Sphyrnidae	2	0.05
Scomberomorus guttatus	Scombridae	2	0.05
Acanthocybium Solandri	Scombridae	2	0.05
Manta birostris	Myliobatidae	2	0.05
Sphyraena flavicauda	Sphyraenidae	2	0.05
Kyphosus vaigiensis	Kyphosidae	2	0.05
Carangoides fulvoguttatus	Carangidae	2	0.05
Cheilio inermis	Labridae	2	0.05
Epinephelus fuscoguttatus	Serranidae	2	0.05
Albula glossodonta	Albulidae	2	0.05
Stolephorus commersonnii	Engraulidae	2	0.05
Scomberoides sp.	Scombridae	2	0.05
Cheilinus trilobatus	Labridae	2	0.05

Apogon sp.	Apogonidae	2	0.05
Pomadasys olivaceus	Haemulidae	1	0.02
Priacanthus hamrur	Priacanthidae	1	0.02
Parupeneus indicus	Mullidae	1	0.02
Holohalaelurus regani	Scyliorhinidae	1	0.02
Himantura sp.	Dasyatidae	1	0.02
Auxis thazard	Scombridae	1	0.02
Istiophorus sp.	Istiophoridae	1	0.02
Remora remora	Echeneidae	1	0.02
Tetrapturus angustirostris	Istiophoridae	1	0.02
Synodus indicus	Synodontidae	1	0.02
Plectorhinchus gibbosus	Haemulidae	1	0.02
Rhynchobatus djiddensis	Rhinobatidae	1	0.02
Echidna nebulosa	Muraenidae	1	0.02
Epinephelus chlorostigma	Serranidae	1	0.02
Gymnomuraena zebra	Muraenidae	1	0.02
Lethrinus mahsena	Lethrinidae	1	0.02
Lutjanus bohar	Lutjanidae	1	0.02
Bodianus perditio	Labridae	1	0.02
Cirrhitichthys oxycephalus	Cirrhitidae	1	0.02
Lethrinus sp.	Lethrinidae	1	0.02
Stegostoma fasciatum	Stegostomatidae	1	0.02
Lutjanus rivulatus	Lutjanidae	1	0.02
Lutjanus sebae	Lutjanidae	1	0.02
Mugil sp.	Mugilidae	1	0.02
Caranx sp.	Carangidae	1	0.02
Epinephelus fasciatus	Serranidae	1	0.02
Kyphosus cinerascens	Kyphosidae	1	0.02
Myripristis murdjan	Holocentridae	1	0.02
Carcharhinus leucas	Carcharhinidae	1	0.02
Plectorhinchus flavomaculatus	Haemulidae	1	0.02
Acanthopagrus berda	Sparidae	1	0.02
Leiognathus sp.	Leiognathidae	1	0.02
Sardinella gibbosa	Clupeidae	1	0.02
Upeneus taeniopterus	Mullidae	1	0.02
Diagramma pictum	Haemulidae	1	0.02
Synaptura commersonnii	Soleidae	1	0.02
Fistularia petimba	Fistulariidae	1	0.02
Alectis ciliaris	Carangidae	1	0.02
Calotomus spinidens	Scaridae	1	0.02
Upeneus tragula	Mullidae	1	0.02
Siganus stellatus	Siganidae	1	0.02
Acanthopagrus sp.	Sparidae	1	0.02
Polydactylus sextarius	Polynemidae	1	0.02

Pomadasys argenteus	Haemulidae	1	0.02
Lutjonus fulvus	Lutjanidae	1	0.02
Naso brevirostris	Acanthuridae	1	0.02
Leiognathus fasciatus	Leiognathidae	1	0.02
Cephalopholis argus	Serranidae	1	0.02
Total		4269	100.00

Inshore trawl bycatch finfish species sampled in the Malindi-Ungwana Bay

Species	Family	Number sampled (N)	Relative abundance (%)
Pellona ditchela	Clupeidae	1261	14.11
Secutor insidiator	Leiognathidae	1197	13.39
Upeneus taeniopterus	Mullidae	836	9.35
Galeichthys feliceps	Ariidae	769	8.60
Photopectoralis bindus	Leiognathidae	457	5.11
Johnius amblycephalus	Sciaenidae	410	4.59
Fistularia petimba	Fistulariidae	405	4.53
Leiognathus equulus	Leiognathidae	303	3.39
Upeneus sulphureus	Mullidae	298	3.33
Pomadasys maculatus	Haemulidae	271	3.03
Otolithes ruber	Sciaenidae	226	2.53
Leiognathus lineolatus	Leiognathidae	208	2.33
Polydactylus sextarius	Polynemidae	187	2.09
Johnius dussumieri	Sciaenidae	143	1.60
Nemipterus zysron	Nemipteridae	130	1.45
Leiognathus daura	Leiognathidae	114	1.28
Gerres filamentosus	Gerreidae	112	1.25
Bothus mancus	Bothidae	103	1.15
Gerres oyena	Gerreidae	85	0.95
Thryssa vitrirostris	Engraulidae	80	0.89
Trichiurus lepturus	Trichiuridae	78	0.87
Upeneus molluccensis	Mullidae	70	0.78
Sphyraena flavicauda	Sphyraenidae	69	0.77
Sillago sihama	Sillaginidae	68	0.76
Drepane punctatus	Drepanidae	66	0.74
Arius africanus	Ariidae	62	0.69
Saurida tumbil	Synodontidae	60	0.67
Caranx ignobilis	Carangidae	52	0.58
Trachinocephalus myops	Synodontidae	49	0.55
Paraplagusia bilineata	Cynoglossidae	47	0.53
Leiognathus elongatus	Leiognathidae	45	0.50
Lobotes surinamensis	Lobotidae	37	0.41
Psettodes erumei	Psettodidae	35	0.39
Upeneus bensasi	Mullidae	35	0.39
Terapon teraps	Terapontidae	33	0.37
Upeneus vittatus	Mullidae	29	0.32
Pelates quadrilineatus	Terapontidae	27	0.30
Rastrilleger kanagurta	Scombridae	24	0.27
Hilsa kelee	Clupeidae	24	0.27
Platycephalus crocodilus	Platycephalidae	23	0.26
Mulloidichthys vanicolensis	Mullidae	21	0.23
Thysanophrys chiltonae	Platycephalidae	21	0.23
Poecilopsetta natalensis	Pleuronectidae	20	0.22

Upeneus tragula	Mullidae	19	0.21
Pelates quadrilineatus	Terapontidae	18	0.20
Gazza minuta	Leiognathidae	18	0.20
Pomadasys multimaculatum	Haemulidae	17	0.19
Leiognathus filamentosus	Leiognathidae	16	0.18
Aluteres monoceros	Monacanthidae	13	0.15
Leiognathus sp.	Leiognathidae	13	0.15
Gnathanodon speciosus	Carangidae	12	0.13
Pomadasys stridens	Haemulidae	11	0.12
Sardinella gibbosa	Clupeidae	11	0.12
Nemipterus bipunctatus	Nemipteridae	10	0.11
Lutjanus fulviflamma	Lutjanidae	10	0.11
Chirocentrus dorab	Chirocentridae	10	0.11
Apogon negripes	Apogonidae	9	0.10
Cociella crocodilus	Platycephalidae	8	0.09
Arothron immaculatus	Tetraodontidae	8	0.09
Terapon jarbua	Terapontidae	7	0.08
Siganus canaliculatus	Siganidae	7	0.08
Spratelloides delicatulus	Clupeidae	7	0.08
Arius sp.	Ariidae	7	0.08
Nemipterus taeniopterus	Nemipteridae	6	0.07
Suarida tumbil	Synodontidae	6	0.07
Alectis indicus	Carangidae	6	0.07
Scomberomorus commerson	Scombridae	6	0.07
Mene maculata	Menidae	5	0.06
Paramonacanthus frenatus	Monacanthidae	5	0.06
Scomberomorus leopardus	Scombridae	5	0.06
Sphyraena putmiae	Sphyraenidae	4	0.04
Platycephalus indicus	Platycephalidae	4	0.04
Apogon fasciatus	Apogonidae	4	0.04
Drepane longimanus	Drepanidae	4	0.04
Platax orbicularis	Ephippidae	4	0.04
Diodon hystrix	Diodontidae	4	0.04
Sorsogona portuguesa	Platycephalidae	3	0.03
Dasyatis uarnak	Dasyatidae	3	0.03
Carcharhinus melanopterus	Carcharhinidae	3	0.03
Himantura gerrardi	Dasyatidae	3	0.03
Thryssa malabarica	Engraulidae	3	0.03
Trachurus trachurus	Carangidae	2	0.02
Scomberoides tol	Carangidae	2	0.02
Lethrinus lentjan	Lethrinidae	2	0.02
Epinephelus malabaricus	Serranidae	2	0.02
Tylosurus crocodilus	Belonidae	2	0.02
Stolephorus sp.	Engraulidae	2	0.02
Murreinosox cinereus	Muraenesocidae	2	0.02
Carcharhinus sealai	Carcharhinidae	2	0.02

Lutjanus sanguineus	Lutjanidae	1	0.01
Caranx armata	Carangidae	1	0.01
Epinephelas mera	Serranidae	1	0.01
Callionymus gardineri	Callionymidae	1	0.01
Priacanthus hamrur	Priacanthidae	1	0.01
Synodus foetens	Synodontidae	1	0.01
Pseudobalistes fuscus	Balistidae	1	0.01
Saurida undosquamis	Synodontidae	1	0.01
Stolephorus commersonnii	Engraulidae	1	0.01
Caranx ferdau	Carangidae	1	0.01
Argyrops filamentosus	Sparidae	1	0.01
Pterois volitans	Scorpaenidae	1	0.01
Siganus sutor	Siganidae	1	0.01
Zanclus cornutus	Zanclidae	1	0.01
Lagocephalus sceleratus	Tetraodontidae	1	0.01
Apistus carinatus	Apistidae	1	0.01
Scorpaena sp.	Scorpaenidae	1	0.01
Terapon puta	Terapontidae	1	0.01
Parastromateus niger	Carangidae	1	0.01
Carcharhinus sp.	Carcharhinidae	1	0.01
Lethrinus harak	Lethrinidae	1	0.01
Bothus sp.	Bothidae	1	0.01
Arothron stellatus	Tetraodontidae	1	0.01
Sphyraene jello	Sphyraenidae	1	0.01
Leiognathus fasciatus	Leiognathidae	1	0.01
Total		8940	100.00

Offshore trawl bycatch finfish species sampled in the Malindi-Ungwana Bay

Species	Family	Number sampled (N)	Relative abundance (%)
Leiognathus lineolatus	Leiognathidae	1469	18.64
Trachinocephalus myops	Synodontidae	1026	13.02
Bothus mancus	Bothidae	935	11.86
Callionymus gardineri	Callionymidae	434	5.51
Upeneus bensasi	Mullidae	399	5.06
Upeneus taeniopterus	Mullidae	317	4.02
Poecilopsetta natalensis	Pleuronectidae	291	3.69
Aluteres monoceros	Monacanthidae	204	2.59
Apogon fasciatus	Apogonidae	183	2.32
Leiognathus elongatus	Leiognathidae	140	1.78
Synodus foetens	Synodontidae	132	1.67
Photopectoralis bindus	Leiognathidae	96	1.22
Secutor insidiator	Leiognathidae	89	1.13
Cyprinocirrhites polyactis	Cirrhitidae	84	1.07
Pseudanthias cooperi	Serranidae	82	1.04
Teixeirichthys jordani	Pomacentridae	81	1.03
Upeneus tragula	Mullidae	81	1.03
Lethrinus elongatus	Lethrinidae	78	0.99
Scolopsis bimaculatus	Nemipteridae	77	0.98
Thysanophrys chiltonae	Platycephalidae	59	0.75
Dascylus trimaculatus	Pomacentridae	53	0.67
Sphyraena flavicauda	Sphyraenidae	53	0.67
Chaetodon pleucopleura	Chaetodontidae	52	0.66
Mulloidichthys vanicolensis	Mullidae	52	0.66
Pellona ditchela	Clupeidae	50	0.63
Pomadasys maculatus	Haemulidae	49	0.62
Parupeneus macronema	Mullidae	46	0.58
Lutjanus lutjanus	Lutjanidae	42	0.53
Lethrinus lentjan	Lethrinidae	39	0.49
Upeneus sulphureus	Mullidae	39	0.49
Nemipterus bleekeri	Nemipteridae	38	0.48
Chaetodon kleinii	Chaetodontidae	31	0.39
Iniistius pavo	Labridae	31	0.39
Saurida tumbil	Synodontidae	31	0.39
Nemipterus sp.	Nemipteridae	30	0.38
Apogon quadrifasciatus	Apogonidae	30	0.38
Gerres oyena	Gerreidae	29	0.37
Caesio teres	Caesionidae	29	0.37
Scolopsis vosmeri	Nemipteridae	26	0.33
Caranx armata	Carangidae	25	0.32
Plectorhinchus pictus	Haemulidae	25	0.32
Apogon aureus	Apogonidae	24	0.30
Leiognathus daura	Leiognathidae	23	0.29
Lagocephalus guentheri	Tetraodontidae	22	0.28
Trachurus trachurus	Carangidae	21	0.27
Sillago sihama	Sillaginidae	21	0.27
Fistularia petimba	Fistulariidae	20	0.25
Apogon apogonides	Apogonidae	20	0.25
Bothus mariestus	Bothidae	20	0.25
Dendrochirus brachypterus	Scorpaenidae	19	0.24
Sargocentron diadema	Holocentridae	17	0.22

Siganus sutor	Siganidae	17	0.22
Polydactylus sextarius	Polynemidae	17	0.22
Leiognathus equulus	Leiognathidae	16	0.20
Canthigaster valentini	Tetraodontidae	16	0.20
Cheilinus trilobatus	Labridae	15	0.19
Johnius dussumieri	Sciaenidae	15	0.19
Plectorhinchus gaterinus	Haemulidae	14	0.18
Lethrinus nebulosus	Lethrinidae	14	0.18
Otolithes ruber	Sciaenidae	14	0.18
Gnathanodon speciosus	Carangidae	13	0.16
Synodus jaculum	Synodontidae	13	0.16
Arius africanus	Ariidae	13	0.16
Cociella crocodilus	Platycephalidae	12	0.15
Gerres filamentosus	Gerreidae	12	0.15
Scomber japonicus	Scombridae	12	0.15
Pempheris schwenkii	Pempheridae	11	0.14
Synodus variegatus	Synodontidae	11	0.14
Lethrinus variegatus	Lethrinidae	11	0.14
Pomacentrus sp.	Pomacentridae	11	0.14
Apogon taeniatus	Apogonidae	10	0.13
Cheilinus diagrama	Labridae	10	0.13
Apogon negripes	Apogonidae	9	0.11
Canthigaster bennetti	Tetraodontidae	9	0.11
Scolopsis aurata	Nemipteridae	9	0.11
Synodus sp.	Synodontidae	9	0.11
Mulloidichthys flavolineatus	Mullidae	9	0.11
Pelates quadrilineatus	Terapontidae	9	0.11
Sufflamen sp.	Balistidae	9	0.11
Paramonacanthus frenatus	Monacanthidae	8	0.10
Caranx ignobilis	Carangidae	8	0.10
Lactoria cornuta	Ostraciidae	8	0.10
Pterocaesio tile	Caesionidae	8	0.10
Apistus carinatus	Apistidae	7	0.09
Gymnocranius grandoculis	Lethrinidae	7	0.09
Cirrhitichthys oxycephalus	Cirrhitidae	7	0.09
Diodon hystrix	Diodontidae	7	0.09
Epinephelus caeruleopunctatus	Serranidae	7	0.09
Siganus canaliculatus	Siganidae	6	0.08
Himantura gerrardi	Dasyatidae	6	0.08
Nemipterus metopias	Nemipteridae	6	0.08
Pseudanthias squamipinnis	Serranidae	6	0.08
Rhinopias eschmeyeri	Scorpaenidae	6	0.08
Chaetodon auratus	Chaetodontidae	6	0.08
Rastrilleger kanagurta	Scombridae	6	0.08
Acanthurus gahhm	Acanthuridae	5	0.06
Lethrinus miniatus	Lethrinidae	5	0.06
Calotomus spinidens	Scaridae	5	0.06
Lutjanus sanguineus	Lutjanidae	5	0.06
Pterois volitans	Scorpaenidae	5	0.06
Scomberomorus leopardus	Scombridae	5	0.06
Galeichthys feliceps	Ariidae	5	0.06
Acanthurus sp.	Acanthuridae	4	0.05
Halichores zeylonicus	Labridae	4	0.05
Platycephalus crocodilus	Platycephalidae	4	0.05

Drepane punctatus	Drepanidae	4	0.05
Acanthurus dusumieri	Acanthuridae	4	0.05
Lutjanus kasmira	Lutjanidae	3	0.04
Platycephalus sp.	Platycephalidae	3	0.04
Zanclus cornutus	Zanclidae	3	0.04
Psettodes erumei	Psettodidae	3	0.04
Aeoliscus punctulatus	Centriscidae	3	0.04
Parupeneus barberinus	Mullidae	3	0.04
Dactyloptena orientalis	Dactylopteridae	3	0.04
Thryssa vitrirostris	Engraulidae	3	0.04
Leiognathus fasciatus	Leiognathidae	3	0.04
Platax orbicularis	Ephippidae	3	0.04
Scorpaena sp.	Scorpaenidae	3	0.04
Pomacanthus semicirculatus	Pomacanthidae	3	0.04
Synodus gracilis	Synodontidae	3	0.04
Archamia fucata	Apogonidae	2	0.03
Lutjanus fulviflamma	Lutjanidae	2	0.03
Priacanthus hamrur	Priacanthidae	2	0.03
Saurida undosquamis	Synodontidae	2	0.03
Alectis indicus	Carangidae	2	0.03
Lagocephalus scleratus	Tetraodontidae	2	0.03
Sufflamen chrysopterum	Balistidae	2	0.03
Canthigaster rivulata	Tetraodontidae	2	0.03
Plectorhinchus schotaf	Haemulidae	2	0.03
Terapon teraps	Terapontidae	2	0.03
Thryssa malabarica	Engraulidae	2	0.03
Bodianus sp.	Labridae	2	0.03
Heteropriacanthus cruentatus	Priacanthidae	1	0.01
Heniochus acuminatus	Chaetodontidae	1	0.01
Naso brevirostris	Acanthuridae	1	0.01
Parascorpaena mossambica	Scorpaenidae	1	0.01
Solenostomus paradoxus	Solenostomidae	1	0.01
Sufflamen fraenatus	Balistidae	1	0.01
Tetrosomus concatenatus	Ostraciidae	1	0.01
Saurida gracilis	Synodontidae	1	0.01
Chilomycterus reticulatus	Diodontidae	1	0.01
Leptoscarus vaigeinsis	Scaridae	1	0.01
Coris caudimacula	Labridae	1	0.01
Chaetodon dolosus	Chaetodontidae	1	0.01
Ctenochaetus strigosus	Acanthuridae	1	0.01
Gymnocaesio gymnoptera	Caesionidae	1	0.01
Lepidozygus tapeinosoma	Pomacentridae	1	0.01
Naso brachycentron	Acanthuridae	1	0.01
Parapriacanthus ransonneti	Pempheridae	1	0.01
Pseudobalistes fuscus	Balistidae	1	0.01
Synodus variegatus	Synodontidae	1	0.01
Caranx cilliaris	Carangidae	1	0.01
Caranx fasciatus	Carangidae	1	0.01
Petroscirtes breviceps	Blenniidae	1	0.01
Remora remora	Echeneidae	1	0.01
Pterocaesio pisang	Caesionidae	1	0.01
Acanthurus fowleri	Acanthuridae	1	0.01
Labroides dimidiatus	Labridae	1	0.01
Chaetodon guantheri	Chaetodontidae	1	0.01

Dasyllus sp.	Pomacentridae	1	0.01
Epinephelus sp.	Serranidae	1	0.01
Pomacentrus caerulus	Pomacentridae	1	0.01
Acanthurus blochii	Acanthuridae	1	0.01
Sphyraena putmiae	Sphyraenidae	1	0.01
Spratelloides delicatulus	Clupeidae	1	0.01
Carangoides ferdau	Carangidae	1	0.01
Paraplagusia bilineata	Cynoglossidae	1	0.01
Scomberomorus commerson	Scombridae	1	0.01
Scolopsis ghanam	Nemipteridae	1	0.01
Cephalopholis urodeta	Serranidae	1	0.01
Apolemichthys xanthurus	Pomacanthidae	1	0.01
Pterois miles	Scorpaenidae	1	0.01
Lethrinus harak	Lethrinidae	1	0.01
Scolopsis bimaculata	Nemipteridae	1	0.01
Ostracion cubicus	Ostraciidae	1	0.01
Arothron hispidus	Tetraodontidae	1	0.01
Epinephelus albomaginatus	Serranidae	1	0.01
Aprion virescens	Lutjanidae	1	0.01
Scorpaenopsis oxycephala	Scorpaenidae	1	0.01
Samaris cristatus	Samaridae	1	0.01
Sardinella gibbosa	Clupeidae	1	0.01
Scolopsis aurata	Nemipteridae	1	0.01
Abalistes stellatus	Balistidae	1	0.01
Total		7882	100.00

Curriculum Vitae

Personal information

Name:	Cosmas Nzaka Munga
Date of birth:	7th January 1976
Nationality:	Kenyan
Marital status:	Married
Languages:	English, Swahili, Rabai
Current address:	P.O. Box 81651 – 80100, Mombasa, Kenya
Emails:	cosmasnke2001@yahoo.com/cmunga@kmfri.co.ke
Telephone:	+254 735 979 383/+254 712 42 62 62

Education

September 2013:	Ph.D. in Marine Sciences from the Department of Biology, Marine Biology Research Group, Gent University, Belgium.
	Thesis title: " *Ecological and socio-economic assessment of Kenyan coastal fisheries: The case of Malindi-Ungwana Bay artisanal fisheries versus semi-industrial bottom trawling*".
September 2008:	Master of Science Degree in Ecological Marine Management, Vrije Universitiet Brussel (VUB), Belgium.
	Thesis title: *Ecological and Socio-economic assessment of the Mombasa Marine National Park and Reserve, Kenya.*
December 2000:	Bachelor of Science Degree in Fisheries and Aquatic Sciences, Moi University, Eldoret, Kenya.
	Dissertation title: "*Growth and feeding habits of African catfish (Clarias gariepinus) in the first four weeks post-hatch in selected ponds at Sagana fish farm, Kenya*".

Working experience

2009 to date:	Research Officer II with Kenya Marine and Fisheries Research Institute, Mombasa, Kenya.
2005 – 2008:	Assistant Research Officer with Kenya Marine and Fisheries Research Institute, Mombasa, Kenya.
2001 – 2004:	Fisheries Officer with Coast Development Authority, Mombasa, Kenya.

Professional trainings

September 2011:	*Benguela Current Commission (BCC) Nansis survey database* workshop, Windhoek, Namibia.
July 2009:	South West Indian Ocean Fisheries Project (SWIOFP) fisheries training, Oceanographic Research Institute, Durban, South Africa.
Sept – Oct. 2005:	Advanced International Training Programme on Sustainable Coastal Development, Gothenburg, Sweden.

Professional affiliations

South West Indian Ocean Fisheries Commission (SWIOFC)

Western Indian Ocean Marine Science Association (WIOMSA)

Kenya Sea Turtle Conservation Committee (KESCOM)

Awards

2012 – 2013:	IFS Research Grant for ecological and socio-economic impact of spear fishing in selected areas along the Kenya coast.
2009 – 2013:	VLIR Ph.D. ICP scholarship
2006 – 2008:	VLIR UOS scholarship for master programme
2005 – 2006:	Marine Research Grant (MARG 1), WIOMSA for preliminary survey of the structure and dynamics of the coastal migrant fishery in Kenya.
Sept – Oct 2005:	WWF-EFN Professional Development Grant.

Peer reviewed publications

Munga, C.N., Mwangi, S., Ong'anda, H., Ruwa, R., Manyala, J., Groeneveld, J.C., Kimani, E., and Vanreusel, A. (2013). Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys. *Fisheries Research* 147: 93 - 102

Munga, C.N., Mohamed, O.S.M., Amiyo, N., Dahdouh-Guebas, F., Obura, D.O. and Vanreusel, A. Status of coral reef fish communities within the Mombasa Marine Protected Area, Kenya, more than a decade after establishment. *Western Indian Ocean J. Mar. Sci.* 10(2): 169-184

Munga, C. N., Ndegwa, S., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J. and Vanreusel, A. (2012). Bottom shrimp trawling impacts on species distribution and fishery dynamics: Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fisheries Science* 78: 209 - 219

Aura, C.M., **Munga, C.N.**, Kimani, E.N., Manyala, J.O. and Musa, S. (2011). Length-weight relationships for nine deep sea fish species off the Kenyan coast. *Pan-American Journal of Aquatic Sciences* 6(2): 188-192.

Munga, C.N., Mohamed, O.S.M., Obura, D.O., Vanreusel, A. and Dahdouh-Guebas, F. (2010). Resource users' perceptions on continued existence of the Mombasa Marine Park and Reserve, Kenya. *Western Indian Ocean J. Mar. Sci.* 9(2): 213-225.

Fulanda B, **Munga, C.**, Ohtomi J, Osore M, Mugo R. and Hossain Y. (2009). The structure and evolution of the coastal migrant fishery of Kenya. *Ocean & Coastal Management*, 52: 459 – 466.