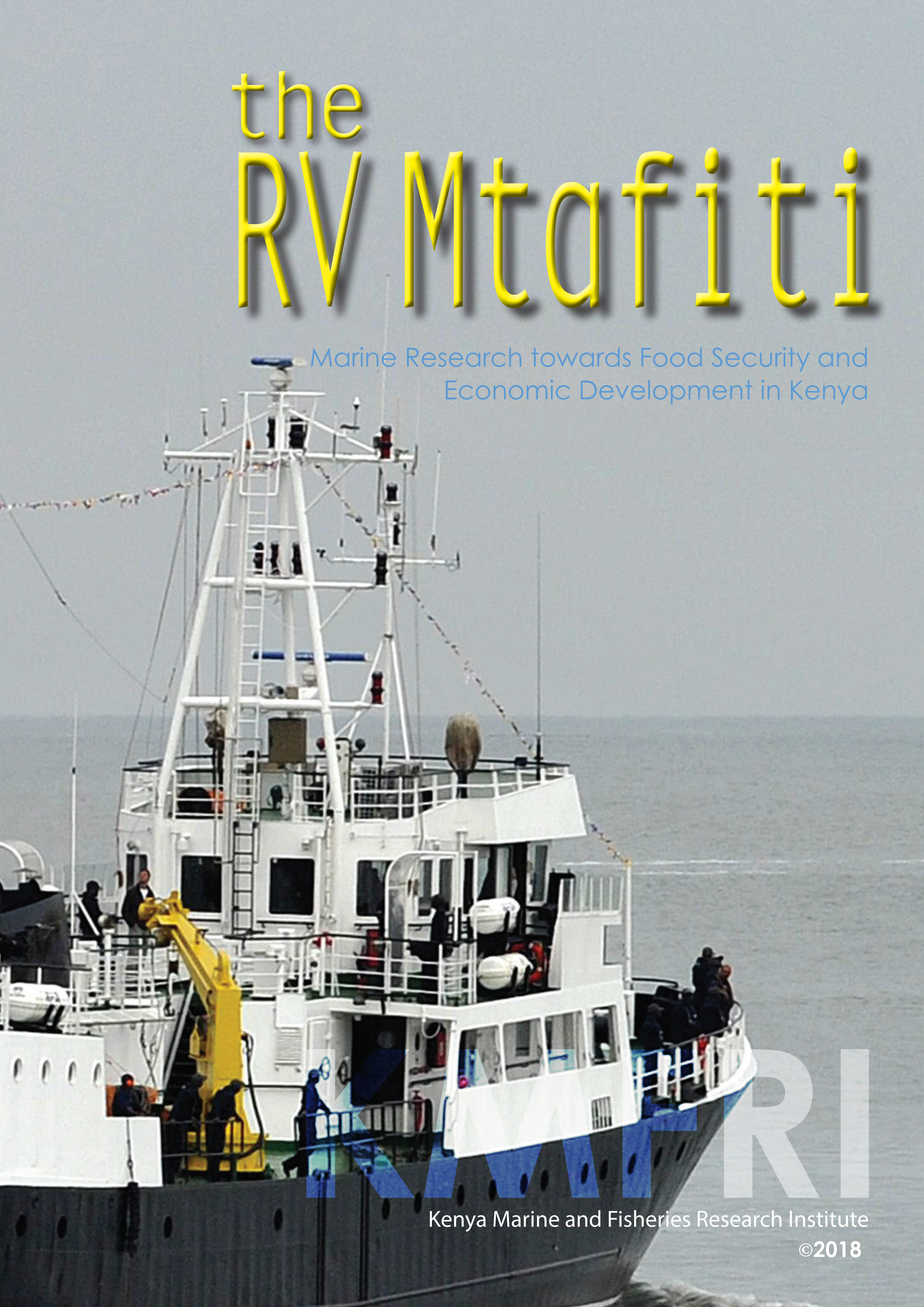

the RV Mtafiti

Marine Research towards Food Security and Economic Development in Kenya

KMFRI

Kenya Marine and Fisheries Research Institute

the RV Mtafiti

Marine Research towards Food Security and Economic Development in Kenya

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Memorable quotes on Knowledge

"In vain have you acquired knowledge if you have not imparted it to others?"
Deuteronomy Rabbah (c.900), Commentary on the Book of Deuteronomy

"In teaching others we teach ourselves"
Traditional proverb

"Sharing your knowledge with others does not make you less important"
Unknown

"An investment in knowledge always pays the best interest"
Benjamin Franklin (1706 – 1790), One of the Founding Fathers of the United States of America

"If you have knowledge, let others light their candles in it"
Margaret Fuller (1810 – 1850), Journalist, Critic and Women's Rights Activist

"A candle loses nothing by lighting another candle"
Father James Keller (1900 – 1977), Roman Catholic priest

"Knowledge increases by sharing but not by saving"
Kamari aka Lyrikal (1978), Californian YouTube musician

"Share your knowledge. It is a way to achieve immortality"
Dalai Lama XIV

"In today's environment, hoarding knowledge ultimately erodes your power."

"If you know something very important, the way to get power is by actually sharing it"
Joseph L. Badaracco & John Shad

"Sharing knowledge can seem like a burden to some but on the contrary, it is a reflection of teamwork and leadership"
Unknown

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We are grateful for the enormous support and sterling leadership given to the institute by KMFRI Board of Management under the chairmanship of Prof. Peninah Aloo-Obudho. With the slogan bestowed upon us by then Board Chairman "… *all going an extra mile*", we indeed made it.

We cannot forget the Kenya Navy through the Chief of Defence Forces General Samson Mwathethe and the Kenya Navy Commander Major General Levi Mughalu for availing competent officers and staff for navigation, maintenance and security during the cruises. Special thanks goes to the following vessel commanding officers: Majors Mulumba, Mayaka, Kariuki and Owino, and Captain Toniok. We are appreciative of the Government of Flanders of the Royal Kingdom of Belgium and in particular the Director of VLIR, Dr. Jan Mees, and scientists at the Flanders Marine Institute (VLIZ) for providing initial capacity building in the Western Indian Ocean (WIO) region to support RV Mtafiti cruises.

This book could not have been possible without the KMFRI scientists who burnt the mid-night candle to achieve this feat. Our gratitude goes to all KMFRI support divisions and especially the procurement headed by Mr Kojo Owiti and Finance Department steered by Mr Abraham Kagwima for the various valuable roles they played in making our dream have having the first *RV Mtafiti* book come true. Bravo to all who supported the team in one way or another. God bless you all.

The culmination of the book was through the leadership of KMFRI Director Prof. James Njiru with a strong support from Deputy Director Oceans and Coastal Systems, Dr. Renison Ruwa and his team of Assistant Directors, Dr. Edward Kimani and Dr. Charles Magori.

List of contributors: Dr. Renison Ruwa, Dr. Edward Kimani, Dr. Charles Magori, Mr. Harrison Ong'anda, Dr. Joseph Kamau, Dr. James Mwaluma, Dr. Gladys Okemwa, Dr. Nina Wambiji, Mr. Johnstone Omukoto, Mr. Amon Kimeli, Mr. Noah Ngisiang'e, Dr. Eric Okuku, Ms. Amina Makori, Dr. Jacob Ochiewo and Ms. Diana Mathai.

Contents

Preamble

Marine resources are among the key natural assets with the potential to support sustainable economic development of Kenya. National food security and nutrition, employment and contribution to Gross Domestic Product (GDP) are the main goals of the Ministry of Agriculture Livestock and Fisheries in line with the policy direction for the period of the economic development plan 2013-2030 as envisioned in Kenya's Vision 2030. Many thousands of people depend on the marine environment as a source of income to meet basic needs. The importance of maintaining or increasing economic benefits from the marine sector is envisaged in Kenya's Blue Economy initiative.

Sound scientific information is one of the key cornerstones for sustainable utilization of marine resources and, coupled with resource management, Monitoring Control and Surveillance functions, supports investment and contribution to the economy. This book on RV Mtafiti has been put together to highlight the potential impacts of our ocean resources on the Kenya economy and the role of deep sea research in harnessing these resources. The book may also stimulate interest of our youth in marine and aquatic science. We hope to continue communicating our research through similar outputs to continuously inform the users of our marine resources.

I would like to appreciate the efforts of the scientists, the people at the centre of research planning, implementation, data capture and interpretation, analysis and reporting. I also appreciate the initiative of the Belgian Ambassador to Kenya, Roxane de Bilderling who led the way by meeting the Kenyan Minister for Fisheries Development, Amason Kingi on 5th November, 2012 in the Ministry Headquarters and agreed that an Inter-Ministerial Team visits Belgium to undertake due diligence to confirm that RV Mtafiti was in good order.

Prof Japheth Micheni Ntiba, CBS
Principal Secretary
State Department of Fisheries, Aquaculture and the Blue Economy

Foreword

The RV Mtafiti was donated to Kenya in 2014 by the Government of Belgium as a result of research cooperation spanning about 35 years. This donation was as a result of a Cooperation Agreement between VLIZ and KMFRI that was signed on October 19, 2012 in Mombasa, Kenya and witnessed by the Governor of West Flander, Governor Carl Decaluwe and the then Permanent Secretary in the Ministry of Fisheries Development, Prof. Japheth Ntiba.

Key highlights of this cooperation included support for research equipment, data and information management, MSc and PhD trainings in marine sciences, and joint research and scientific publications. The hallmarks of these journey were varied and the apex of which was the acquisition of the research vessel signifying one of the greatest achievements in the development of marine science in Kenya and the Western Indian Ocean (WIO) region. In order for KMFRI to position itself at the frontier of ocean research a number of initiatives were realised over the years.

Much work was done in the Kenyan waters by a number of research vessels both for resource surveys and oceanography. The RV Fridtjof Nansen conducted surveys off the continental shell in the 1980s. During the same period RV Ujuzi and RV Manihine did some exploratory fishing in Kenya. In the 1990s, the Netherlands Indian Ocean Program teamed up with Kenyan scientists aboard the RV Tyro for extensive surveys off the Kenyan EEZ on biodiversity, water quality and sea conditions. These missions were perfectly timed to complete the nearshore ecological work that had been on-going under the Kenya Belgium Project from the mid 80's. It was therefore with great pleasure that Kenya engaged with Belgium in various fora to consolidate this dynamic engagement.

The introduction of RV Mtafiti in the Indian Ocean has come in with a lot of opportunities as well as challenges. The regional partners have expressed a lot of optimism on implementing a number of regional survey initiatives including the on-going International Indian Ocean Expedition (IIOE-2) and other activities aligned to the Sustainable Development Goals (SDGs). The platform is also now adequately equipped to train marine scientists in the region. On the other hand, thresholds for marine scientists remain a big challenge as various skills are under represented both in absolute numbers and gender balance. In Kenya fresh knowledge is now emerging on the ecology and resource potential of our EEZ with important implications for support to the Blue Economy initiative. It is in this perspective that RV Mtafiti continues to play a central role in the management of our ocean's natural resources nationally in Kenya and regionally in the Indian Ocean.

Prof. James M. Njiru (PhD)
Director – KMFRI

List of Key Acronyms

CAS	Catch Assessment Survey
CPUE	Catch per Unit Effort
DWFN	Distant Water Fishing Nations
EACC	East African Coastal Current
EAMFRO	East Africa Marine Fisheries Research Organisation
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization
EAF	Ecosystem Approach to Fisheries Management
GDP	Gross Domestic Product
GEF	Global Environment Facility
HAB	Harmful Algal Bloom
IIOE	International Indian Ocean Expedition
IOC	Intergovernmental Oceanographic Commission
IOCINCWIO	Intergovernmental Oceanographic Commission for Cooperative Investigation in the North and Central Western Indian Ocean
IODE	International Oceanographic Data and Information Exchange
IOTC	Indian Ocean Tuna Commission
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
IUCN	International Union Conservation of Nature
IUU	Illegal Unregulated and Unreported
KBP	Kenya Belgium Project
KCDP	Kenya Coastal Development Project
KES	Kenya Shillings
KeFS	Kenya Fisheries Service
KMFRI	Kenya Marine and Fisheries Research Institute
MCS	Monitoring Control and Surveillance
MoU	Memorandum of Understanding
MPA	Marine Protected Area
Mt	Metric Tonnes
NASA	National Aeronautical and Space Agency
NEM	Northeast Monsoon
NKB	North Kenyan Banks
NM	Nautical Miles
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Centre
NORAD	Norwegian Agency for Development Cooperation

ODINAFRICA	Ocean Data and Information Network for Africa
QC	Quality Control
RECOSCIX-WIO	Regional Cooperation in Scientific Information Exchange in the Western Indian Ocean
SC	Somali Current
SDF	State Department for Fisheries
SDG	Sustainable Development Goals
SEC	South Equatorial Current
SECC	Southern Equatorial Counter Current
SEM	Southeast Monsoon
SOPs	Standard Operating Procedures
SWIO	South West Indian Ocean
SWIOFP	South West Indian Ocean Fisheries Project
UNCLOS	United Nations Convention on Law of the Sea
UNDP	United Nations Development Programme
UNESCO	United Nations Education and Scientific Cultural Organization
VLIR	Flemish Interuniversity Council
VLIZ	Flanders Marine Institute
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association

Chapter One

FUNCTIONS AND STRATEGIC FOCUS OF KMFRI

1.1 Introduction

The State of Kenya has a total land area coverage of about 582,650km^2 with a coastline of about 650km which borders with Somalia in the North and Tanzania in the South. The coastal land area is about 32,447km^2 and lies in a semi-arid zone. Kenya's oceanward boundary extends to the 200NM Exclusive Economic Zone (EEZ) limit in accordance with the United Nations Convention on Law of the Sea (UNCLOS) proclamation and has further applied to extend to 350NM limit for exploitation of ocean bed resources (Fig. 1.1). The additional application of 150NM will provide an additional 103,000km^2 bringing a total ocean cover of 350NM and 245,000km^2 which makes about 42% of Kenya's total land area.

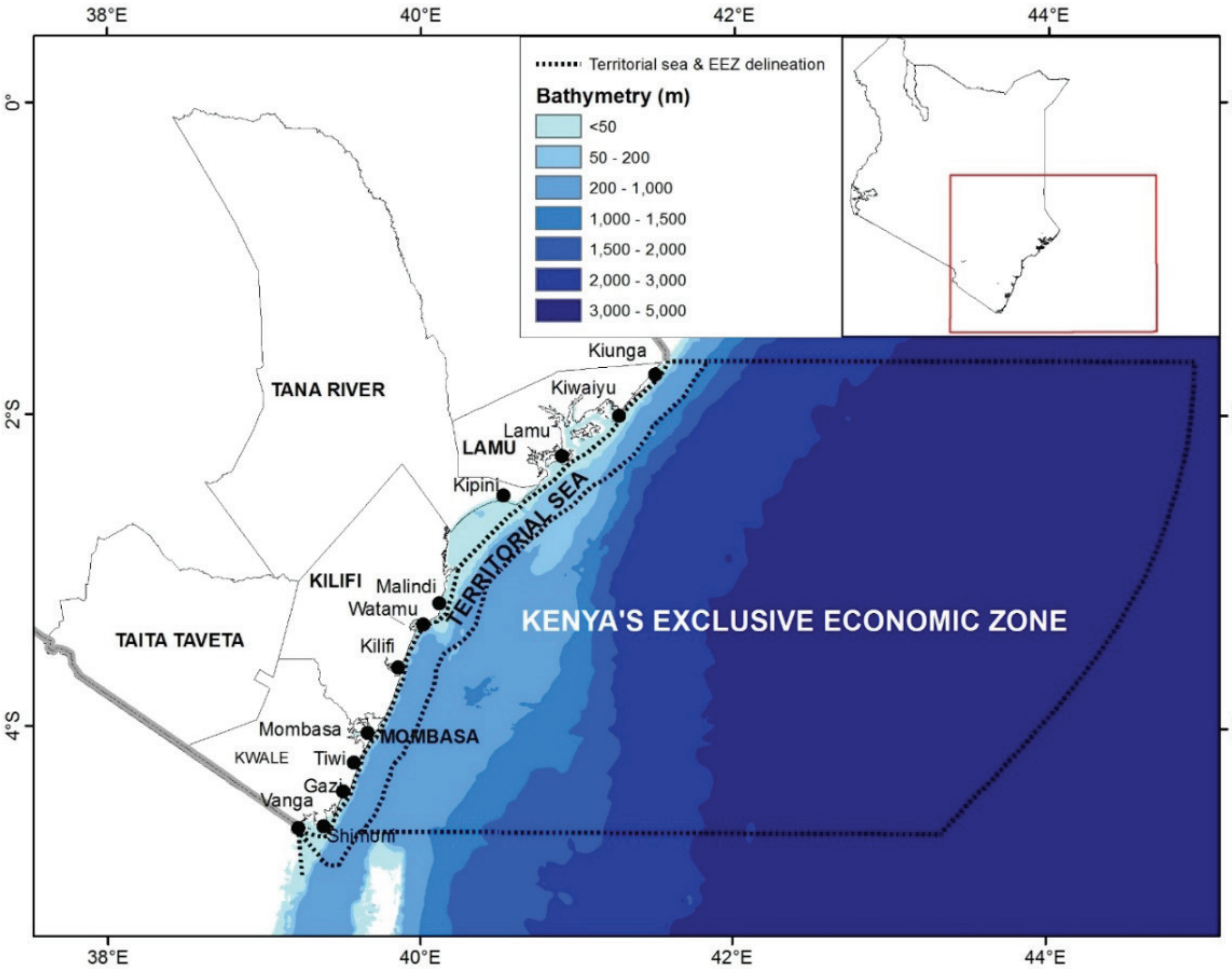

Figure 1.1: Map of Kenya's Exclusive Economic Zone according to the Presidential Proclamation Legal Notice No. 82

1.2 Functions of KMFRI

Kenya Marine and Fisheries Research Institute (KMFRI) is a State Corporation established in 1979 by the Science and Technology Act, Cap 250 of the Laws of Kenya, which has since been repealed by the Science, Technology and Innovation Act No. 28 of 2013. The Act recognizes KMFRI as a national research institution under section 56, fourth schedule. KMFRI's mandate is to undertake research in marine and freshwater fisheries, aquaculture, environmental and ecological studies, including chemical and physical oceanography, in order to provide scientific data and information for sustainable exploitation, management and conservation of Kenya's fisheries and other aquatic resources; and to contribute to National strategies on food security, poverty alleviation, clean environment and creation of employment as provided for under Kenya's Vision 2030. Specifically, the roles of KMFRI according to Legal Notice No. 7 of 1979 are to:

a) Conduct multidisciplinary and collaborative research on fish ecology, population dynamics, stock assessment and general aquatic ecology;

b) Collect and disseminate scientific information on fisheries and other aquatic resources and related natural products;

c) Study and identify suitable species for culture including development, adoption and transfer of rearing technology and procedure;

d) Study chemical and physical processes that affect productivity of aquatic ecosystems;

e) Monitor water quality and pollution in fresh and marine water environments;

f) Carry out socio-economic research on aspects relevant to fisheries, environment and other aquatic resources;

g) Establish a marine and freshwater collection for research and training purposes;

h) Offer training facilities to aquatic scientists;

i) Conduct research on fish quality control, post-harvest preservation and value addition technologies.

1.3 The Strategic Focus of KMFRI

Four key results areas have been identified including seven strategic objectives and formulated based on national laws and policy documents, and emerging global issues identified in the KMFRI Corporate Strategic Plan 2016-2020 (KMFRI, 2016). These have been developed in line with, the Constitution of Kenya 2010, Fisheries Management and Development Act, 2016, Kenya Vision 2030 (Government of Kenya, 2007), Medium Term Plan II, Executive Order No. 1/2016 on organization of the Government of the Republic of Kenya, UN Oceans and Sustainable Development Goals under the 2030 Agenda for Sustainable Goals (UN 2017a), the Impacts of Climate changes in the atmosphere on the Oceans (UN, 2017b) and Conservation and Sustainable use of Marine Biological Diversity of Areas beyond national Jurisdiction (UN 2017c) .

Each of the key result areas has strategic objectives to be achieved, strategies that will be put in place and the activities to be carried out. The key result areas are:

1. Research and innovation;
2. Technological transfer and community outreach;
3. Resource mobilization and institutional capacity building;
4. Collaboration and partnerships.

Result Area 1: Research and innovation

KMFRI's core mandate is aquatic research and in-novation and has the following strategic objectives.

Strategic Objective 1	To conduct quality, innovative, demand-driven and relevant research in coastal and oceanic ecosystems
Strategic Objective 2	To undertake research on promotion of investments in the Blue Economy
Strategic Objective 3	To disseminate research information and innovative technologies to stakeholders

For implementation of these three strategic objectives, various activities have been developed to provide for monitoring and evaluation.

Result Area 2: Transfer of technology and

community outreach

Strategic Objective 4	To increase community participation and promote outreach programs

To increase the economic harvests from both the coastal and oceanic deep sea areas there is need to improve and adopt new technology and teach the communities how to use these improved or new technologies. For centuries local communities have only been able to utilize resources in shallow coastal waters and therefore it is important to train them to fish in deep waters with improved fishing gears using the RV Mtafiti.

Result Area 3: Resource mobilization and institutional capacity building

Strategic Objective 5	To mobilize financial and human resources to implement KMFRI's core functions and develop research infrastructure
Strategic Objective 6	To strengthen institutional structure and capacity

RV Mtafiti is itself a major contribution in institutional capacity building as it facilitates undertaking of offshore research. Its operational budget is high and thus the need for resource mobilization to support infrastructure and capacity building to support the research undertaken by the vessel. Fulfilling the following two objectives under the Key result area 3 will enhance the efficient use of RV Mtafiti.

Result Area 4: Collaboration and partnerships

Strategic Objective 7	To promote local and international collaboration and partnerships

High impact research is a product of multidisciplinary collaboration and partnerships of various institutions and stakeholders. There is a need to create working relationships through Memoranda of Understandings (MOUs) with private and public sectors towards identifying need driven research by stakeholders and establish ways of funding the research. In the new governance dispensation in Kenya where most functions have been devolved to the County Governments there is an urgent need to work in partnership with the County Governments to ensure sustainable use and long-term conservation of the natural resources. This result area has the following strategic objective:

1.4 Ocean and Coastal Systems Research

The research function of KMFRI, as provided in the Strategic Plan 2006-2020, is divided into three Divisions: Ocean and Coastal Systems research, Fresh Water research and Aquaculture (KMFRI, 2016). The Ocean and Coastal Systems Research has got two main functional departments including the Oceanography and Hydrography and Ocean and Coastal Fisheries Research Departments while the Aquaculture and Social Economics Departments are cross-cutting in both Divisions.

Oceanography and Hydrography Research Department

The Oceanography and Hydrography Department deals with physical, chemical, biological and geological oceanography of the offshore and near shore waters. Sea level monitoring is carried out to generate data to forecast tidal variations along the Kenya coast and to detect extreme oceanic events such as storm surges but can also capture signals of cyclone and tsunami when they occur. The Department is also responsible for research on sustainable use and protection of aquatic resources in marine waters, critical habitats such as mangroves, seagrass beds and corals, monitoring and documenting the physical (including geological) and chemical characteristics (water quality, pollution and nutrient dynamics) of the various aquatic ecosystems to determine natural and human induced changes. In addition, the Department undertakes studies on the interrelationships between biota and their aquatic environments in relation to fisheries, aquaculture and conservation of biodiversity. The Department supports Integrated Coastal Zone Management (ICZM) approach in the management of coastal and marine resources by providing the required data and information.

Ocean and Coastal Fisheries Research Department

The overall goal of the Ocean and Coastal Fisheries Research Department is to provide competent scientific information and data on the sustainable use of fishery resources through ecosystem management approach. The Department is responsible for inventorying and assessment of fish stocks, their spatial and temporal abundance and distribution, fish ecology and biology, and population dynamics. Post-harvest technology and value addition research is also undertaken by the Department. Post-harvest technology and value addition includes fish handling and processing, investigating and isolating active substances from aquatic plants and animals for industrial, medicinal and nutritional values. The department is also responsible for fish safety and quality assurance.

Mariculture Research Department

The Mariculture Research and Development Department is responsible for all research related to coastal and ocean farming. Through this Department, KMFRI has been responsible for investigating new and adaptive culture species and techniques for enhanced fish and fisheries production in different culture systems. The Directorate has also invested in technologies in seed (fingerlings) production, feed formulation and production, hatchery development and operations techniques, the appropriate stocking levels for different production systems, in addition to genetic and hormonal manipulation for increased production in mariculture systems.

Socio-economics Department

The Socioeconomics Department focuses on establishing cost-effective methods for sustainable exploitation of the oceanic and impacts on the environment by promoting stakeholder participation including local communities. The Department tracks the socio-economic impacts of fisheries and other resources management activities and undertakes studies on food security, livelihoods, fish marketing and supply channels for both processed and unprocessed products, evaluation of the economic viability of aquaculture including mariculture initiatives, and economic valuation of aquatic ecosystems. It further taps indigenous knowledge for integration into management strategies for aquatic resources.

1.5 National Challenges

Fisheries, including aquaculture as a sector continues to play an important role in the social and economic development of Kenya. Currently, the sector is a major source of rural employment which is in line with the government policy of reducing rural-urban migration. Over 5 million Kenyans depend on the sector directly or indirectly as a source of livelihoods, employment and other economic sustenance. The sector also provides fish to nearly eight out of every ten households in the country. The demand for fish as food has increased over the years, including in traditionally non-fish eating communities. The fisheries sector faces a number of development challenges that require appropriate action supported by relevant research and monitoring. These challenges include but not limited to the following:

Declining fish stocks: Fish stocks in shallow inshore waters of the Indian Ocean have been declining over time due to overexploitation owing to excessive increase in fishing effort, destructive fishing practices, pollution, high post-harvest losses, inadequate enforcement of regulations and environmental degradation. Decline in fish stocks leads to loss of employment and food security, and ultimately to resource use conflicts.

Domestic capacity for deep sea fishing: The artisanal fishers in the marine waters have limited fishing technologies that hinder them from venturing into semi-industrial and industrial fisheries in the deep waters which are rich in tuna and tuna-like species. The tuna and tuna-like species are therefore currently exploited by distant water fishing vessels that do not land their catch in Kenya thus, denying the country employment opportunities, income, food security, revenue and raw material for the fish processing industries. This situation is a result of inadequate domestic investment in deep sea fishing.

Mariculture development: Kenya has got a competitive advantage for aquaculture in terms of access to diverse fresh and marine water resources that include ocean waters, springs, wetlands, rivers, water reservoirs and other temporary water bodies. The country's vast water system and diverse climatic conditions favours the farming of a wide variety of fish species and other aquatic species. The potential area for fish farming stands at 1.4 million hectares of which only 3.9 % (about 55,000 hectares) is utilized. This has largely been attributed to inadequate supply of certified quality fish seed (fingerlings) essentially due to lack of hatcheries and species-specific feeds as well as the high cost of inputs for the small scale fish farmers.

Marketing and value-chain infrastructure: The fishers and fish farmers are compelled to sell their fish at prices dictated by the buyers as they fear the high post- harvest losses. Lack of well-developed marketing facilities, functioning supply chains and market information systems both in rural and urban areas is a serious constraint. In addition, inadequate marketing and value-chain infrastructure are an impediment to fisheries development and growth in the country. This reduces the bargaining power and profitability of the fish producers as fish is highly perishable.

Value addition: The bulk of Kenya's fish and fishery products are usually marketed without much value addition due to low investments in micro-processing occasioned by among other factors, limited access to electricity especially in the rural areas and limited adoption of appropriate technologies for new product development. This reduces the value of fish and the returns to the producers.

Human resource capacity and infrastructure: Both the public and private sector have inadequate capacity for marine and fisheries research and development. These include capacity in areas such as fish processing, marketing, marine geology, oceanography, hydrography, anthropology, sociology, economics, geophysics, climatology, biotechnology, and marine engineering, navigation, marine engineers and marine crew. According to the Food and Agriculture Organisation (FAO) oceans, seas, coastal areas and the associated blue economy are critical to global and national economic development (FAO, 2016). However, factors like unsustainable coastal development are contributing to irreversible damage to habitats affecting ecological functions and biodiversity.

Climate change and ocean acidification are compounding such impacts at a time when the rising global population requires more fish as food. FAO is promoting "Blue Growth" as a coherent approach for the sustainable, integrated and socio-economically sensitive management of oceans and wetlands. However, inadequate capacity to tackle bio-prospecting, inadequate research, bio-piracy and illegal unregulated unreported (IUU) fishing are major challenges in many parts of the world. The Sustainable Development Goals (SDGs) have also opened a new frontier for research globally. KMFRI will contribute to realization of these goals as elaborated in Table 1.1.

Table 1.1: Sustainable development goals relevant to the KMFRI mandate (Government of Kenya, 2007; KMFRI, 2016; United Nations, 2017a)

SDG #	Goal description	Contribution by KMFRI
1	Ending poverty in all its forms	Provide appropriate innovative technology to improve livelihoods and income generation
2	Ending hunger, achieving food security and improved nutrition	Providing scientific information to support management and development of capture fisheries, aquaculture, and reduction of post-harvest losses
5	Achieving gender equality and empowerment of women and girls	Engaging women and girls in technology transfer and providing equal employment opportunities
13	Climate action to combat climate change and its impacts	Generation of information for mitigation of impacts of climate change, and promotion of carbon trading
14	Conservation and sustainable use of the oceans, seas and marine resources for sustainable development	Provision of scientific information to guide management decisions
17	Partnerships for sustainable development	Strengthening collaborations and partnerships in research for sustainable development

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Chapter Two

COLLABORATION AND CAPACITY BUILDING IN MARINE RESEARCH

2.1 Introduction

KMFRI has collaborated with many institutions, projects and individual scientists globally, regionally and nationally. Collaborations are guided by institutional Strategic Plan of 2016-2020 where Strategic objective 7 aims at "*Promoting local and international collaboration and partnerships*". *The Strategy employed is to "Develop and strengthen collaboration and linkages with partners and stakeholders at the local, regional and international levels"***.** KMFRI's collaboration and partnerships are anchored in a number frameworks. The Blue Economy initiative is currently championed by FAO as an approach for the sustainable, integrated and socio-economically sensitive management of oceans and wetlands. The Sustainable Development Goals (SDGs) have also opened a new frontier for research globally. The following are some of the relevant collaborative programs and projects.

2.2 The Kenya Belgium Collaboration

The Kenya-Belgium Project (KBP) in marine sciences was launched in January 1985 as a collaboration between the Free University of Brussels and KMFRI as host, with Prof. Phillip Polk as the Director of the project following an MoU signed between the two institutions. From 1986 onwards, other institutes and universities from Belgium and Kenya got involved and stronger interdisciplinary research emerged. The institutions from Belgium were the Universities of Ghent, Leuven, Limburg, Antwerp, and the Institute for Marine Research while the institutions from Kenya were the Universities of Nairobi, Kenyatta, Moi and the Kenya Wildlife Service, besides KMFRI as the host.

The KBP consisted of three successive phases with the general aim to achieve long-term management of the coastal zone through both fundamental and applied research. The main priorities were to increase the protein production and other valuable products from the sea and to reduce the degradation and destruction of the marine environment for short-term profits. The First Phase of KBP, named "Cooperation in the field of Marine Ecology and Management of the Coastal Zone" was sponsored by the Administration for Belgian Development Cooperation (ABOS) and was headed by Prof. Phillip Polk.

The KBP started by investing in basic laboratory equipment, computers, vehicles and a zodiac rubber dinghy for inshore sampling. To provide training in marine research, a postgraduate course was started at the VUB, named the Fundamental and Applied Marine Ecology directed to scientists from developing countries and led to the degree in Master of Science. Overall, approximately 70 scientists from KMFRI were offered funding to go to Belgium to either obtain an MSc or PhD degree, or to participate in workshops or additional training programs. Many students and professors from Belgian visited Kenya to conduct research within the framework of the collaboration (Plate 2.1)

Phase 1 represented the first fundamental research efforts directed at the inventory and description of the fauna and flora at Gazi Bay at the south coast of Kenya. During the same time, Prof. Polk assisted by Dr. Ruwa set up a small-scale oyster farm at Gazi Bay using his extensive expertise in oyster culture in Belgium (Plate 2.2).

Plate 2.1: Prof. M. H. Daro of VUB supervising a field experiment on the zooplankton of Gazi Bay, Kenya

Plate 2.2: KMFRI technicians inspect oyster culture racks set-up at the Gazi Bay, Kenya (Photo credit: Dr. Renison K. Ruwa)

Phase 2 of KBP between 1989 and 1992 was called "*Higher Institute for Marine Sciences*" with funding from the Flemish Interuniversity Council (VLIR) for another four years. The main objective was to conduct fundamental research in the areas of plankton studies, reef ecology, water chemistry, coastal oceanography and modeling, fisheries, algae, pollution and library resources. Two European Commission-funded projects followed focusing on the dynamics of mangrove ecosystems and the link between mangroves, seagrass beds and coral reefs (project 1: "*Dynamics and Assessment of Kenyan Mangrove Ecosystems*" (1990-1992) and project 2: "*Interlinkages between Eastern-African Coastal Ecosystems*" (1993-1995)). Within these projects, besides Kenya and Belgium, different institutions in the Netherlands, Italy, Mozambique, Tanzania, Sweden and Portugal joined and started collaborating intensively. The projects were facilitated and coordinated by the KBP and they represented a continuation and widening of the ongoing KBP.

Phase 3 was a logical extension of the KBP started 1992-1996 with a VLIR sponsored project named "*Research Towards Sustainable Exploitation of Natural Resources in Mangrove Forests*". This goal was to implement the most promising fundamental research results obtained before 1993 and continue with research on fish, crustaceans, birds, algal, phytoplankton, and pollution monitoring. Two of the most acknowledgeable research applications were:

- The development of Africa's largest oyster farm in Gazi Bay set up KMFRI contained about 600,000 oysters. In 1995, the farm was extended to Shirazi and worked with a local women group, the Shaza Women group, under the supervision of Dr. Jan Seys and funding from the Section Development Cooperation of the Belgian Embassy to Kenya under its micro-intervention program.
- The reforestation of more than 10 hectares of mangrove forest (90,000 trees of 5 different mangrove species) in 1994 under

the lead of Dr. James Kairo (then a student of Dr. David van Speybroeck).

Funding for a fourth extension of KBP was not viable because of a change in policy stating that development cooperation between institutes and universities were no longer allowed. Thereafter, VUB collaborated with UoN and partner universities in the project Ecological Marine Management (ECOMAMA), and KMFRI was retained to provide technical support and supervision of post graduate students. Thanks to years of support by the Belgian Government, KMFRI has been recognized as "*Regional Centre of Excellence in Marine Sciences*" within the East-African Region. It now fulfils important roles within the regional organizations including the WIOMSA and the IOC Regional Committee for the cooperative investigation in the North and Central Western Indian Ocean (IOCINCWIO).

Plate 2.3: Top: Aerial view of Gazi Bay, Kenya during the early 1990s showing the application of research in oyster farming and mangrove re-forestation. Bottom: Mr. Stephen Mwangi, a KMFRI scientist, guides students around the mangrove experimental plot during a training session of the Ecological Marine Management course at Gazi Bay

The RV Tyro Expedition: The Netherlands Marine Research Foundation organized a one-year Indian Ocean expedition on board the RV Tyro (Plate 2.4) in 1992. The expedition fell within the frame of the "*Netherlands Indian Ocean Program*" (NIOP) which was implemented from 1990-1995. The expedition set out to conduct offshore and coastal research and was complementary to the ongoing research under the KBP and EC projects in Kenya. The central theme of Kenya's program was to study the effects of the monsoonal regime on coastal marine systems through the Project "*Monsoons and Coastal Ecosystems in Kenya*".

The Netherlands Government through the Netherlands Geosciences Foundation and its predecessors the Netherlands Marine Research Foundation and the Netherlands Council of Oceanic Research ventured into blue ocean research. The execution of the Snellius II Programme in the mid-1980s and the Indian Ocean Programme (1990-1995) were instrumental in reaching these goals. The fast developments during the 1980s were reflected in the wide variety and quantity of equipment on board RV Tyro during the expedition phase of the Programme. RV Tyro had Kenyan, Pakistani

Plate 2.4: RV TYRO sailing in the Indian Ocean (Source: www.nioz.nl)

and Seychellois scientists working together with the Dutch colleagues. The central theme of the multi-disciplinary Indian Ocean Programme was "*Global Change*", and was geared towards studying the spatial and temporal effects of the monsoons on the marine ecosystem in the area. The Progamme also supported many scientists to pursue further education and enhanced infrastructure capacity at KMFRI.

A detailed description of the Programme is given in the "Scientific Programme Plan of the Netherlands Indian Ocean Programme 1990-1995". The operations of the expeditions covered the Northeast Monsoon (NEM) and the Southeast Monsoon (SEM) seasons for the area south of the equator. The main part of the expedition phase was carried out on board RV Tyro alongside a land-based project carried out in June-July 1992 in the coastal area of Kenya, for which a containerized laboratory facility was set up at Gazi south of the Kenya. During the expedition, port calls were made at Port Said (Egypt), Mombasa (Kenya), Djibouti (Djibouti), Victoria (Seychelles) and Karachi (Pakistan).

RECOSCIX-WIO Project (1989-1991): The Regional Cooperation in Scientific Information Exchange in the Western Indian Ocean (RECOSCIX-WIO), a scientific information exchange project (1989-1991) was initiated by Mr. Peter Pissierssens, a student of Prof. Phillip Polk, and his Kenyan Counterpart Mr. Hezbone Onyango. The project was funded by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and was aimed at providing scientists with all relevant publications and enhancing communication between the marine scientists, active at the East African coast, but also outside the region. Through RECOSCIX-WIO, KMFRI became the first government institution in Africa to acquire internet connectivity. The University of Limburg (LUC) further coordinated this program as it was extended by VLIR (RECOSCIX-WIO II) until 1995. KBP cooperated strongly with this project, since all scientists could benefit from the availability and exchange of scientific information and communication.

***ODINAFRICA*:** The Ocean Data and Information Network for Africa (ODINAFRICA), interlinked with RECOSCIX-WIO, has been one of the most successful projects of the International Oceanographic Data and Information Exchange (IODE) Programme of the Intergovernmental Oceanographic Commission of UNESCO (IOC). ODINAFRICA was a collaboration between more than 40 marine related institutions from 25 countries in Africa namely: Angola, Benin, Cameroon, Comoros, Congo Brazzaville, Cote d'Ivoire, DR Congo, Egypt, Gabon, Ghana, Guinea, Kenya, Madagascar, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Nigeria, Senegal, Seychelles, South Africa, United Republic of Tanzania, Togo and Tunisia. The overall objective of ODINAFRICA was to address the challenges faced in accessing data and information for coastal management. The funding for the project was from the IOC of UNESCO and the Government of Flanders, the Kingdom of Belgium. ODINAFRICA aimed to address the challenges faced in ensuring that ocean and coastal data and information generated in national, regional and global programmes are readily available to a wide range of users in an easily available format.

The focus of the current phase of the project is strengthening the pan African network of National Oceanographic Data Centre (NODCs), and marine related institutions, as a sustained mechanism for application of data, information and products in marine and coastal management in Africa. This includes the development of linkages with data generators (including on-going large-scale projects on the African coasts), and the development of targeted products and services for national and regional end users. This will enable them demonstrate their roles as national facilities and encourage other projects to deposit their data in the NODCs, thereby making them sustainable. Starting with the implementation of the project on Regional Cooperation in Scientific Information Exchange in the Western Indian Ocean region (RECOSCIX-WIO) in 1989, IODE has focused on development of the capacity and infrastructure for the collection, processing, archival, analysis, interpretation and dissemination of data and information products.

2.3 The RV Mtafiti: Evolution and Capacity

The RV Mtafiti (Plate 2.5) was formerly the Flemish Government's oceanographic research vessel RV Zeeleeuw, and was officially handed over to the Government of Kenya on 3 May 2013. The donation of the vessel fell within a collaboration between Flanders Marine Institute (VLIZ) and KMFRI. The two institutes signed a formal Memorandum of Understanding (MoU) for bilateral collaboration in the field of marine sciences on 19th October 2012. RV Mtafiti was navigated from Oostend, Belgium to Mombasa, Kenya on a Kenyan flag by the Kenya Navy crew, a journey that took 33 sailing days through the Suez Canal. The President of Kenya H.E. Uhuru Kenyatta officially commissioned the RV Mtafiti on the 27th January, 2014 at the Kilindini Harbour in Mombasa (Plate 2.6). RV Mtafiti continues to serve marine research in Kenya, managed by KMFRI. The specifications of the vessel are shown in Table 2.1.

Plate 2.5: RV Mtafiti in Kilindini Harbour at the Port of Mombasa, Kenya

Table 2.1: The specifications of RV Mtafiti

Parameter	Measurement
Vessel length	55.6 m
Beam	9.0 m
Draught	3.65 m
Power	1192 KW
2 Engines	750-080 A
Maximum speed	14.5 knots
Crew number including scientists	47 persons

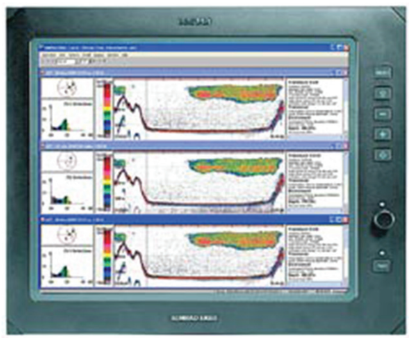
2.4. Research equipment

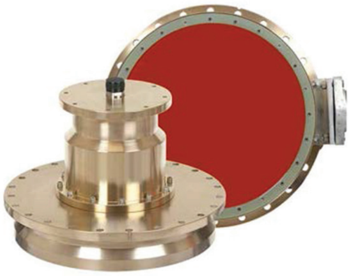
The success of the Kenya's Blue Economy initiative is increasingly dependent on scientific and technological innovations. The country faces environmental challenges affecting the world including global warming, food security and improvement of quality of life. All of these areas depend upon strong innovation capabilities that require access to the highest quality research infrastructure. The infrastructure provide platforms for scientists to do outstanding research at the global, regional and national level. KMFRI is making efforts to develop the research infrastructure required through support from the government and collaborating institutions.

RV Mtafiti came with pre-installed research equipment (DGPS, Personal Computers, Van Veen grab, Niskin bottle, water purification system, Conductivity Temperature Depth (CTD) profiler, Fume hood and Thermo-salinograph. KMFRI has procured additional research equipment including boats, calibration bench, a Single split beam Simrad EK60 hydroacoustics echo sounder, Teledyne Acoustics Doppler current profiler, CTD rosette, bongo nets among others. These will ensure seamless calibration, sampling, processing, analysis and dissemination of research products of universal standards. Table 2.2 presents the infrastructural capacity of RV Mtafiti demonstrating its capability to conduct oceanographic research.

Plate 2.6: The President of Kenya H.E. Uhuru Kenyatta (Left) officially commissioning RV Mtafiti at the Kilindini Harbour in Mombasa by handing over the wheel of RV Mtafiti to the Commanding Officer Major Phillip Mulumba on the 27th January, 2014

Table 2.2: The research equipment on board RV Mtafiti, specifications and samples or data collected.

Type of	Equipment specifications	Equipment visual	Samples/data collected
Simrad EK60 Scientific Echo sounder	The Simrad EK60 is a split-beam Windows (TM) operated echo sounder with built-in calibration. It operates three echo sounder frequencies simultaneously namely 38, 120 and 333 kHz. The EK60 is specifically suited for permanent installation onboard a research vessel. The Simrad EK60 is modular, and one can assemble any combinations of transceivers and transducers to fit their research purposes		Fish abundance, Biomass, schools, Bottom mapping, bathymetry, Zooplankton
Multi-parameter calibration and test bench	A Time Electronics work station bench that is designed for calibration installed in its Mombasa center lab. It is offered with modules that adjusts electrical pressure, temperatures, and loops. It's availed with other optional modules such as power supplies, oscilloscopes, and counters		Calibrates temperatire, Ph, Conductivity probes, Pressure devices, multimeter,voltimeter etc
General Oceanic Intelligent Rosette Water Sampling System	Rosette waterbottle system with G.o.'s intelligent rosette water sampling system for 12 positions of 5 liters niskin water sampler size rosette includes: the submersible array, hanger, adaptor plates, rechargable battery pack, interconnecting cable, software and one operations manual 40" (102cm) dia x 36"(91cm) h, weight 116lbs (53kg) without bottles		Water quality, nutrients

Ocean Surveyor Acoustic Doppler and Current Profiler	A 150 KhZ ADCP Capable of collecting detailed data of the distribution of water currents and suspended materials through the water column and along the ship's path		Hydrography-(currents) water mass movement
SBE 21 SeaCAT Thermosalinograph	Externally powered thermosalinograph for shipboard determination of sea surface (pumped-water) conductivity and temperature. Internal memory, acquisition of NMEA navigational data and remote temperature data, and capability to interface with auxiliary sensors.		Continuous sea surface, temperature and salinity data collection
Phytoplankton nets	Phytoplankton-net with in situ flow meter		Phytoplankton species abundance, algal blooms
Zooplankton nets	WP2 (180 my), Juday (90 my), Multinet medium (-180 my), Echo sounders (EK 80)		Distribution and abundance of fish larvae zooplankton
Conductivity Temperature and Depth profiles (CTD)	SBE 19plus V2 with optional SBE 5P pump, SBE 43 dissolved oxygen sensor, and cage -- Plumbing with Y-fitting and air bleed valve, Conductivity cell guard		For measurement of conductivity, temperature, depth; dissolved oxygen, ph, etc on ocean water
Sediment grab	Van Veen Grab Sampler with 600m lowering cable		Sea bottom sediment samples for sediment analysis, chemical analysis, determination of infauna

Piston Corer	3m Galvanized steel gravity corer with trigger for gravity coring operations		Sea bottom sediment cores to a depth of 1m for histological sedimentation analysis
Stereo Zoom Camera Microscope	Advanced Stereo Zoom Microscope with LED Top-light + 1080p HDMI Camera		Observation and photography of research samples
Waterproof And Marine Binoculars	Waterproof Binoculars, boating binocular with raised rubber armouring		Observation and identification of sea birds, mammals and sea turtles
Spotting Telescope	Angled spotting scope with variable 25x to 75x magnification and 60mm objective lens, dynamic lens focusing system		Observation and identification of sea birds, mammals and sea turtles

2.5 RV Mtafiti Human Capacity Building

Three key trainings have been undertaken to improve the human capacity for planning and undertaking marine research cruises:

Training on scientific cruise planning, oceanographic sampling, fisheries and data management

The training was undertaken in collaboration with Flanders Marine Institute (VLIZ) from April 18th to 27th 2016. The aim of the training was to enhance approaches to deep sea scientific cruise planning, oceanographic sampling, and data management. The workshop was sponsored by VLIR-UOS, VLIZ, KMFRI and Intergovernmental Ocean Commission (IOC) for Africa. The training objectives were to:

- Create a critical pool of staff in the WIO region and beyond with the capacity to effectively undertake oceanographic research using RV Mtafiti and to act as scientific campaign leaders for their scientific crew during research cruises;
- Ensure the cost-effective use of ship time and guarantee the excellence and quality of data as well as samples collected during surveys and therefore maximize the benefits to be gained from cruises undertaken using RV Mtafiti;

- Create awareness of the availability of RV Mtafiti for regional research campaigns and promote the deployment of RV Mtafiti for joint research and education projects.

Training on hydroacoustics (EK60) set up, calibration, deployment and data collection

The EK60 acoustic equipment personnel training onboard RV Mtafiti was conducted by experts from Kongsberg Simrad who are the manufactures of the equipment. The training took place from the 7th to 12th September 2016 with a team of 16 scientists and technologists, and included the following aspects:

- Initializing (powering) the EK60 transducers, ER60 workstation and NMEA inputs connectivity;
- Calibrating the (EK60) frequencies (38,120 and 333 KHz) ready for deployment;
- Data collection process with the EK60 system;
- The EK60 raw data extraction.

Training on Acoustics Doppler Current Profiler (ADCP) set up, calibration, deployment and data collection

Training on the Acoustics Doppler Current Profiler (ADCP) was undertaken in October 2017 by the supplier, UNIK Ltd. The training took place at the Kenya Navy docks. Two scientists and one technician were trained. Test data was collected during a trial cruise. The modules of the training included the following:

- Initializing the ADCP transducer, ADCP workstation and NMEA inputs connectivity
- Setting and testing the ADCP frequency (150KHz) ready for deployment
- Data collection process and raw data extraction process

Chapter Three

EMERGING ISSUES AND REGIONAL PROGRAMS

3.1 Introduction

The RV Mtafiti is useful in addressing regional as well as national research needs to support the long term economic development needs of Kenya. There are a number of regional opportunities to participate in the collection of oceanographic data to inform emerging issues and regional research initiatives. The key regional programmes include the following:

3.2 The International Indian Ocean Expedition

The idea of the International Indian Ocean Expedition was first considered by the Scientific Commission on Ocean Research in 1957, who then formed working groups comprising a number of scientists to strategize on how to stimulate international cooperation in ocean sciences. The Programme, which was christened (International Indian Ocean Expedition) IIOE-1, was implemented from 1959 to 1965 (UNESCO, 1965). The legacy of IIOE included training of oceanographers on the ships of other countries other than their own, stimulating interest in marine science in many countries and developing national organisations. The program was carried out by individuals, institutions and countries and involved international co-ordination and co-operation. A number of charts and atlases of the Indian Ocean have been developed from the data collected including a geological atlas, and a plankton productivity atlas.

The 2nd International Indian Ocean Expedition (IIOE-2) is set to run for a five year period from 2015-2020. The expedition is motivated by the need to advance understanding of geologic, oceanic and atmospheric processes and their interactions in the Indian Ocean. This will contribute in determining how these dynamics affect climate, marine biogeochemical cycles, ecosystems, and fisheries both within the Indian Ocean region and globally. The mission of IIOE-2 is to advance our understanding of the Indian Ocean and its role in the Earth System in order to enable informed decisions in support of sustainable development and well-being of humankind. IIOE-2 outputs are expected to contribute to sustainable development of marine resources; environmental stewardship; ocean and climate forecasting; and training of the young ocean scientists from the region.

Funding for IIOE-2 activities will be principally generated within each country. IIOE-2 will focus on three major areas of science activity namely remote sensing studies, modelling and assimilation studies; and in situ observation and potential for leveraging existing infrastructure. Thus, RV Mtafiti as a platform is of paramount importance to the IIOE-2 initiative. Kenya is committed to deploying RV Mtafiti to take part in the data collection and regional training programmes.

The *IIOE-2 Kenya National Committee* held the 1st planning meeting on 24-28th April 2018 hosted by KMFRI. Besides KMFRI, the representation included the Technical University of Mombasa, Kenya Meteorological Department, the University of Nairobi and the University of Eldoret. At the close of the meeting, the following information needs were prioritized:

1. Increased knowledge on impacts of human induced stressors on marine resources and ecosystems
2. Increased understanding of the vulnerability and resilience of human populations to anthropogenic induced stressors
3. Increased understanding of extreme events (tropical cyclones, tsunamis, volcanic eruptions, earthquakes, sea-level rise, heat waves, flood and drought, coral bleaching, ocean acidification, Harmful Algal Blooms (HABs), and deoxygenated "dead zones" in relation to climate change
4. Improved disaster risk management and adaptation
5. Increased understanding of threats (storm surge, inundation, floods etc) to human populations arising from extreme events

6. Increased knowledge of the location of unique marine geological, physical and ecological features within the Kenyan waters
7. Increased knowledge of biogeochemical cycles and ecosystem dynamics of the unique features in Kenyan waters.

The legacy of IIOE-2 will be the establishment of a firmer foundation of knowledge on which future research can build and on which policy makers can use to make science based decisions on the sustainable management of Indian Ocean ecosystems. RV Mtafiti has been involved in a number of cruises in the Kenyan waters that contribute to the IIOE-2 workplan (Annex I).

3.3 Support to Coastal County Government Integrated Development Plans

The Constitution of Kenya 2010 set up devolved County Governments. The County Governments along the Kenya coast include Kwale, Mombasa, Kilifi, Tana River, and Lamu. The County Government Act No. 12 of 2012 requires a County to develop and implement County Integrated Development Plans as a basis of development activities. Even though RV Mtafiti is most suited for surveys in deep waters due to the vessel tonnage and capacity, it is important to consider the dynamic linkages between nearshore ecosystems and the deep waters. There is a complex mix of natural processes in the nearshore and offshore waters which influence the coastal and marine ecosystem productivity. The impacts of human activities add yet another dimension that must be considered.

Nearshore research is therefore essential in understanding land-based activities impacting on marine environment. Towards this, KMFRI research teams conducted a detailed review of the CIDPs for respective Counties and subsequent County Consultation in May/June 2018. There was a clear a convergence between KMFRI's mandate and a number of livelihood improvement projects identified in each of the Counties. KMFRI has subsequently developed a Nearshore Research Programme to contribute to the development agenda of the Counties.

Through a consultative process, KMFRI has identified priority research areas and gaps to be addressed, to complement RV Mtafiti offshore surveys. The coastal and marine research priorities of the coastal counties, developed during planning meetings with stakeholder conducted in May and June 2018 are shown in Table 3.1. KMFRI research agenda, will focus on the North Kenyan Banks (NKB) and Diani-Pemba channel ecosystems. Of major interest in surveys within the NKB is understanding the upwelling system, the sediment movement from River Tana and the observed high biomass of fish during the RV Mtafiti hydroacoustic surveys. The driver of the Diani-Pemba ecosystem survey is the proposed cross-boundary Marine Protected Area (MPA) between Kenya and Tanzania.

Table 3.1: The fisheries, aquaculture, environment and value addition research interest of the coastal counties and some of the recent research undertaken by KMFRI

Research needs expressed by the coastal counties	Research undertaken by KMFRI
Kwale County	
Fisheries • Fisheries including value addition • Post-harvest loss reduction using racks • Capacity building for fishers • Fish farming **Aquaculture** • Seaweed mariculture **Environment** • Biodiversity assessment and coral reef restoration • Mangrove reforestation	• Fisheries catch assessment • Seaweed mariculture • Oyster farming • Fishing gear experiments including Fish Aggregation Devices (FADs) and dropline • Fish pond farming • Aquarium fisheries • Deep sea fisheries • Coral reef restoration
Mombasa County	
Fisheries • Research and build capacity on use of new fishing gears both in inshore and offshore EEZ • Root cause analysis to mitigate poor compliance levels in governance • Role of fisheries observer Programme in supporting sustainable exploitation, conservation and management **Aquaculture** • KMFRI to partner with Mombasa County to revive the container farming initiative targeting the youth to address rampant unemployment • Conduct a feasibility study on viability of cage farming in selected creeks within Mombasa County **Value Addition** • Research on post-harvest losses and ways of mitigating such losses including value addition. **Environment** • Undertake research on mangrove restoration • Conduct valuation of existing mangrove cover and modalities for carbon trading	• Fisheries catch assessment • Aquarium fisheries • Offshore oceanography • Coral reef ecology • Sea level changes • Pollution • Integrated coastal zone management • Fisheries stock assessment
Kilifi County	
Fisheries • Fisheries stock assessment • Mitigation against post-harvest losses • Develop fisheries management plans • Capacity building and technology transfer **Aquaculture** • Mariculture of marine tilapia in cages and ponds • Maricuture of artemia in salt farms • Introduce hatchery technology • Mariculture of mangrove crab, prawn and milkfish in an environmental friendly way **Environment** • Mangrove reforestation • Biodiversity assessment for mapping co-management marine areas	• Fisheries catch assessment • Seaweed mariculture • Fishing gear experiments including Fish Aggregation Devices (FADs) and dropline • Aquarium fisheries • Deep sea fisheries
Tana River County	

Fisheries • Need to access deep sea fisheries • Enhance gear technology capacity • Establish post-harvest technology demonstrations • Establish areas for cold chain facilities for farm fish processing **Aquaculture** • Support fish farming for fast growing fish species, prawns and crabs • Fingerling production • Feed development • Conduct research on sustainable development for fish, crab and prawn culture **Environment** • Biodiversity assessment to establish community conservation areas in Kipini • Technical support for coral reef restoration in Kipini area Tenawi Island • Shoreline changes in Kipini area	• Fisheries catch assessment • Prawn fishery stock assessment in Ungwana Bay • Mangrove restoration • Seaweed mariculture • Coral reef restoration
Lamu County	
Fisheries • Fisheries and post-harvest technologies • Stock assessment of the lobster • Gear capacity building; pole and line drop line • More spatial planning map potential fishing zones offshore EEZ • Upscale experimental fishing technologies; the pole and line; dropline • Stock assessment for the sea cucumber and the north Kenya bank fisheries • Electronic Market Information System **Aquaculture** • Include aquaculture best candidate species identified but for live bait, that is, mudfish needs identified and planning **Environment** • Biodiversity assessment, including mangrove management plan	• Fisheries catch assessment • Aquarium fisheries • Demersal deep water fishing gear trials • Rapid assessment of the beach seine fishery

3.4 Contribution to the Blue Economy

The Blue Economy refers to the use of the sea and its resources for sustainable economic development, and covers both aquatic and marine spaces including the oceans, seas, coasts, lakes, rivers and underground resources (United Nations Economic Commission for Africa, 2016). Kenya is a signatory to the United Nations Convention on the Law of the Sea (UNCLOS) of 1982 which promotes sustainable exploitation of the seas and oceans. Kenya is also a signatory to Africa's United Nations Agenda 2030 and the Sustainable Development Goals (SDGs) of 2015. SDG 14 particularly focuses on conservation and sustainable use of the oceans, seas and marine resources for sustainable development. Further, Kenya being an independent country, has sovereign rights to explore, exploit, conserve, and manage the natural resources within the areas of her Exclusive Economic Zone (EEZ) and continental shelf.

Priority activities and links with MTP III

Economic investment opportunities in the Blue Economy in Kenya include fishing, aquaculture, tourism, ship building and repair, education and training, marine cargo handling, marine salvage, international shipping, transport, energy, bio-prospecting, offshore mining, marine bio-technology, blue data, aqua-business, cargo consolidation, freight forwarding, marine insurance, bunker supplies, ship-handling, port agency, port services, sports fishing, and marine governance.

Kenya's Blue Economy currently contributes an estimated KES178.8 billion to the GDP annually. (Kenya GDP=KES 7,749,426 million in 2017, Kenya National Bureau of Statistics, 2018). The main productive sub-sectors in the Blue Economy sector include fisheries, aquaculture, tourism, transport, ship building, energy, bio-prospecting and underwater mining and related activities (Government of Kenya, 2018; United Nations Economic Commission for Africa, 2016). The fisheries sub-sector in Kenya accounts for about 0.5% of the Gross Domestic Product. The sub-sector also generates employment for about two million people through fish trade, fish processing, equipment repair, construction of fishing vessels, fishing and other related activities. The sub-sectors have the potential to contribute significantly towards attainment of some of the "Big Four" Government development interventions including Manufacturing, and Food and Nutrition Security.

Fisheries products are also used in the formulation of essential medicines including fish oils which has essential amino acids. About 80% of fishmeal used in animal feeds production is based on fisheries products including '*Omena*' (*Rastrineobola argentea*) and Nile perch by-products Fisheries also benefit other sectors including supply of raw materials for the production of animal feeds in the livestock industry. The rapid development of aquaculture, for the local and export markets, and its rapid transformation in many areas into a commercial or semi-industrial activity is also contributing substantially to the development of rural areas.

Relevant flagship programmes and projects

The following Blue Economy projects and programmes are prioritized by the Government of Kenya, of which research outputs from RV Mtafiti will play a key role in their implementation:

- Development of the Blue Economy master plan
- Development of a national maritime spatial plan;
- Development/review of policy, legal, regulatory and institutional framework for Kenya's Blue Economy;
- Development of an integrated national maritime policy;
- Development of national fishing and maritime fleet supported by clear understanding of the status of fish stocks in our waters;
- Development and management of blue economy database;
- Fish stocks monitoring and frame surveys;
- Marine aquaculture development.

The Blue Economy Committee report recognizes the important roles that KMFRI and RV Mtafiti research based activities will contribute to the above flagship projects. One of KMFRI's strategic focus is to increase community participation and promote outreach programs. Engagement of stakeholders in RV Mtafiti research contributes to the realization of this goal. From time to time a stakeholder analysis will be conducted to gauge the expectations and required interventions relevant to KMFRI's mandate.

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Chapter Four

SCIENTIFIC SURVEY DATA: PERSPECTIVES AND MANAGEMENT

4.1 Introduction

Scientific understanding for management, conservation and planning depends on survey data available to be analysed for trends and develop appropriate policies for sustainable management and conservation of natural resources. Data is collected using appropriate methodologies and standards, classified and archived in databases for trend analyses. Data on coastal and ocean systems in Kenya includes historical periods before and during KBP followed by the surveys using RV Mtafiti. The survey data is archived taking into consideration the following:

- The historical surveys where data is available
- Current data on recent findings to show an interconnection with historical data archiving
- Adopting management of data following ODINAFRICA criteria

Ship based ocean observations in Kenya, mainly on fisheries resources and oceanography, have a long history dating back to colonial times. The data from these observations are often unpublished technical survey reports with limited public circulation. A number of historical reports and data from these observations with the details of the fisheries and oceanographic data are available. However, most of the data sets from these surveys were stored abroad. There were efforts to repatriate some of the historical surveys data sets to the WIO region during SWIOFP with little success. This was due to loss of some data sets, changes in institutional structures over time as well as language barriers.

The challenge of storage and long term archival and dissemination of ocean data has been addressed in various ways. The SWIOFP developed infrastructure and technical capacity at KMFRI to support the archival of the historical data sets as well as the new data collected during the project. The institute has also developed a Data and Knowledge Management Policy in 2016 which provides guidelines for the storage of research data. The RV Mtafiti data collection follows Standard Operating Procedures (KMFRI, 2017) and the generated data sets are archived at the Kenya National Ocean Data Centre (KNODC) at KMFRI. The data is made available to users following the data policy guidelines. In addition, KMFRI is the national node for ocean data within the Ocean Data and Information Network for Africa (ODINAFRICA).

4.2 Historical Scientific Surveys

A lot of data has been amassed from historical resource surveys conducted in the offshore demersal and meso-pelagic zones of Kenya's EEZ waters. Some of the major historical cruise surveys are detailed in Table 4.1. Early survey efforts include *RV Menika* (1964-1969), *RV Shakwe* (1969-1971), and *RV Ujuzi* (1979-1981). The demersal trawl surveys have mostly been done at 200-500m bottom zones, while meso-pelagic resources have been surveyed through hydroacoustics to 500m depth zone.

Table 4.1: Historical cruise surveys in Kenyan EEZ waters

Country	Vessel	Year	Collaborator(s)
Kenya and Tanzania (East Africa Community)	RV Menika, RV Manihine	1964-1969	EAMFRO
Kenya	RV Shakwe	1969-1971	EAMFRO
France	F/V C.I.A.P	1972	Undescribed
Ukraine	RV Prof.Vodynitsky, RV Prof. Mesyastev	1978	Akademik Vernadsky19 Cruise
Kenya	RV Kusi, FV Ujuzi	1978-1979	EAMFRO
Norway	RV Fridtjoff Nansen	1982	FAO, Institute of Marine Research, Bergen, Government of Kenya
Netherlands	RV Tyro	1992	Netherlands Indian Ocean Programme
Germany	RV Pelagia	2000	Undescribed

Dr. Fridtjof Nansen has provided some of the mst consistent data on the fisheries resources of Kenya since the first survey in 1982. This was supplemented by the RV Ujuzi which undertook fishing trials with electric reels, supplemented by handline fishing in the North Kenya Banks (NKB). RV Menika deployed surface and bottom longlines, trolls and trammel nets to assess the tuna-like species, demersal species, and spiny lobster resource. Some of the flag states ships that have conducted surveys in Kenya are listed in the Table 4.2.

More recent surveys include the SWIOFP cruises undertaken in the Kenyan waters from 2009 - 2012. Marine Fishing Vessel (MV) Vega conducted surveys to assess the shallow water crustacean in Ungwana Bay in 2011, but also included several sea properties in compliant with the Food and Agriculture Organization (FAO) Ecosystem Approach to Fisheries (EAF) principles. Among the variables measured included Salinity, Secchi disc depth, Sea Surface Temperature (SST), Dissolved Oxygen (DO), wind direction and wind force (Beaufort scale), chlorophyll-a, total suspended matter, nutrients, bottom sediment organic matter content, grain size, and zooplankton abundance. MV Roberto conducted a similar survey in 2012 for deep water crustaceans off Malindi-Ngomeni-Kilifi and Chale. Unfortunately, no more surveys were conducted by

Table 4.2: RV Fridtjof Nansen research surveys

Year	Sampling method / gear	Cruise code / reference number	Period of research	Number of trawl stations
1980	Two scientific sounders (120 and 38 kHz), two echo integrators, a searchlight sonar (18 kHz) and a net sonde (50 kHz). Bottom trawl was a high opening shrimp trawl, 1800 meshes. Pelagic trawl was 1600 meshes	Cruise 33(1980408)	08 December 1980 – 19 December 1980	47
1982	Two echo sounders, one operating at 38 kHz and one at 120 kHz. Nansen bottles. Demersal trawl. Pelagic trawl	Cruise 53(1982404)	12 August 1982 – 24 August 1982	59
1982	Two echo sounders, one operating at 38 kHz and one at 120 kHz, Nansen bottles, Pelagic and bottom trawls. Demersal longline	Cruise 57(1982407)	07-15 December 1982	31
1983	Two echo sounders, one operating at 38 kHz and one at 120 kHz, connected to echo integrators, Nansen bottles. Demersal trawl: High opening shrimp and fish trawl with rubber bobbins	Cruise 60(1983403)	02 May 1983 – 08 May 1983	60

the time SWIOFP ended in 2013 until the coming of RV Mtafiti.

4.3 Open Data Practice

Data accessibility is enhanced by meta-data, which is a description of the procedures and custody status of the data. Meta-data may be implemented in various levels. In addition, the actual data is required to undergo quality control (QC) guided by five quality values (Table 4.3). Ocean Standards and Best Practices Project (http://www.oceandatastandards.org/) has recommended the use of standard items to facilitate data exchange and recommend strongly the use of Quality Control flags. Data quality flagging ensures that errors and quality of data is known by the user to assess the suitability for the intended use.

Various initiatives on ship survey data exchange exist, and the most visible ones are available in the following portals:

- Nansis database – offline database containing all survey data ever conducted by RV Dr. Fridtjohf Nansen

World ocean database list of cruises (https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html); ICES portal http://ocean.ices.dk/csr/ containing summary and data of various cruises, This is also known as ROSCOPS (Report of Observations/ Samples collected by Oceanographic Programmes) conceived by IOC-UNESCO in late 1960s, which datasets are referenced by Marsden Squares; Seadatanet (https://www.seadatanet.org/Metadata) - data acquired by research vessels and monitoring programmes for the European seas and global oceans; FAO metadata platform (http://www.fao.org/geonetwork/srv/en/main.home), a good example of metadata management and data delivery system, and compliant with ISO19115/19139 metadata format and corresponding XML export form; IOC/UNESCO IODE Ocean data portal (http://www.oceandataportal.org/), a comprehensive platform for sharing oceanographic data from ship surveys all over the world.

These initiatives have evolved to support Open Access principles of data management and therefore compliant with Open Science. This is a fulfilment of the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities which was adopted on 22nd October 2003. The declaration has been signed by a number of governments, universities, research institutions, funding agencies, foundations, libraries, museums, archives, learned societies and professional associations.

Table 4.3: Data quality control (QC) - Five quality values

Value	Primary-level flag labels	Definition
1	Good	Passed required documented QC tests
2	Not evaluated, not available or unknown	Used for data when no QC tests performed or the information on quality is not available
3	Questionable or suspect	Failed non-critical documented metric or subjective test(s)
4	Bad	Failed critical documented QC test(s) or as assigned by the data provider
9	Missing data	Used as a place holder when data is missing

References

KMFRI (2016) Data and knowledge management policy for marine and freshwater research. 4 pp.

KMFRI (2017) RV Mtafiti Standard Operating Procedures. 86 pp

Chapter Five

MAIN FINDINGS USING RV MTAFITI

5.1 RV Mtafiti Research Strategy

5.1.1 Introduction

The acquisition of RV Mtafiti has enabled Kenya Marine and Fisheries Research Institute (KMFRI) and by extension Kenya to venture into deep sea surveys. KMFRI developed the RV Mtafiti Research Strategy in line with KMFRI Corporate Strategic Plan for 2016-2020 to facilitate the implementation of the national research agenda (KMFRI, 2016). The strategy provides the aims and objectives, the implementation and facilitation of RV Mtafiti research between 2014 and 2020 to collect data and information on the marine environment and the resources therein to support exploitation and management planning.

Since the RV Mtafiti arrived in Kenya, it has been equipped with various scientific equipment and undertaken several surveys in the Territorial as well as the EEZ waters (Annex I). The general aim of these surveys is to provide information on the fishery resources and to collect data and samples to describe the biological and physical oceanography of the marine environment. The key objectives of the surveys are to:

1. Conduct hydroacoustic survey to determine fish biomass and distribution within Kenya's EEZ;
2. Collect physical oceanographic data including temperature, salinity, conductivity;
3. Collect sea bottom bathymetric data and biological samples;
4. Measure nutrient profiles and pollution levels within the water column;
5. Determine productivity by undertaking biological surveys on zooplankton, phytoplankton, and fish larvae;
6. Observe the distribution of marine mammals and sea birds;
7. Determine the occurrence and composition of microplastics.

The overall planning for RV Mtafiti surveys takes into consideration various categories of users including the fishing industry, County Governments, the State Department of Fisheries as well as regional and international partners. RV Mtafiti Standard Operating Procedures have been developed to guide the collection and processing of research data and samples (KMFRI, 2017). A summary of the Standard Operating Procedures (SOPs) that have been developed is annexed (Annex II), and the list of datasets collected and archived at KMFRI is provided in Annex III. The following are brief descriptions of the protocols used to achieve the above objectives:

5.1.2 RV Mtafiti research survey plan

To effectively undertake research surveys in the Territorial and EEZ waters, four survey blocks have been delineated: Territorial block (Fig. 5.1.1), from Vanga in the South to Lamu in the North; and three survey blocks in the EEZ: Block 1 off Lamu County, Block 2 off Kilifi County and Block 3 off Kwale County (Fig. 5.1.2). The survey follows a designated cruise track, and also covers the Northeast Monsoon (NEM) and Southeast Monsoon (SEM) seasons to decipher the influence of seasonal dynamics on fish biomass distribution and environment parameters. Consideration of seasonal dynamics is due to the influence of monsoon climate variability which controls the oceanographic features associated with primary and secondary productivity and fish abundance and distribution (detailed in section 4). Specialized surveys dedicated to a particular research theme or area are also planned and undertaken as need arises.

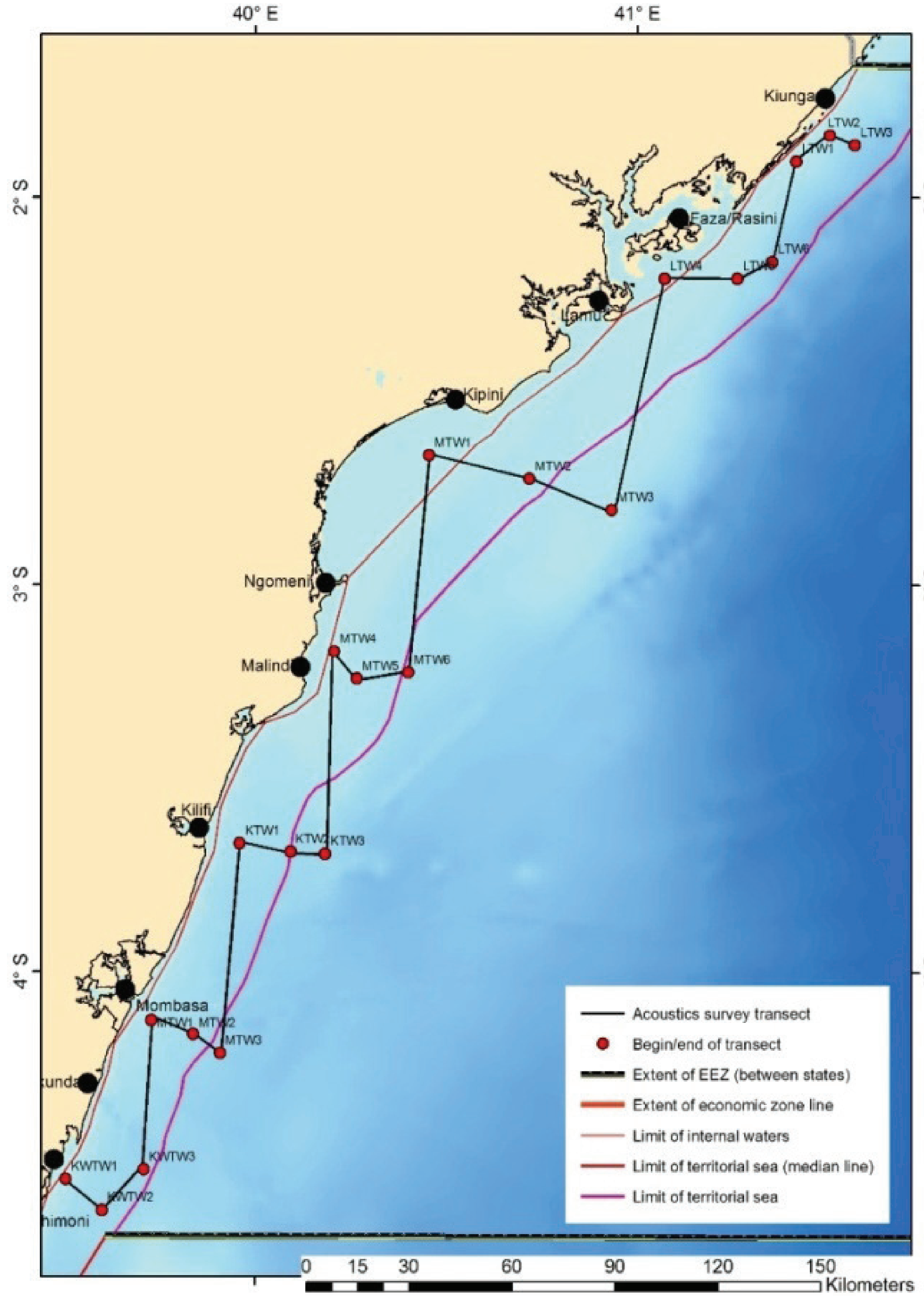

Figure 5.1.1: RV Mtafiti Territorial waters cruise transects and sampling stations

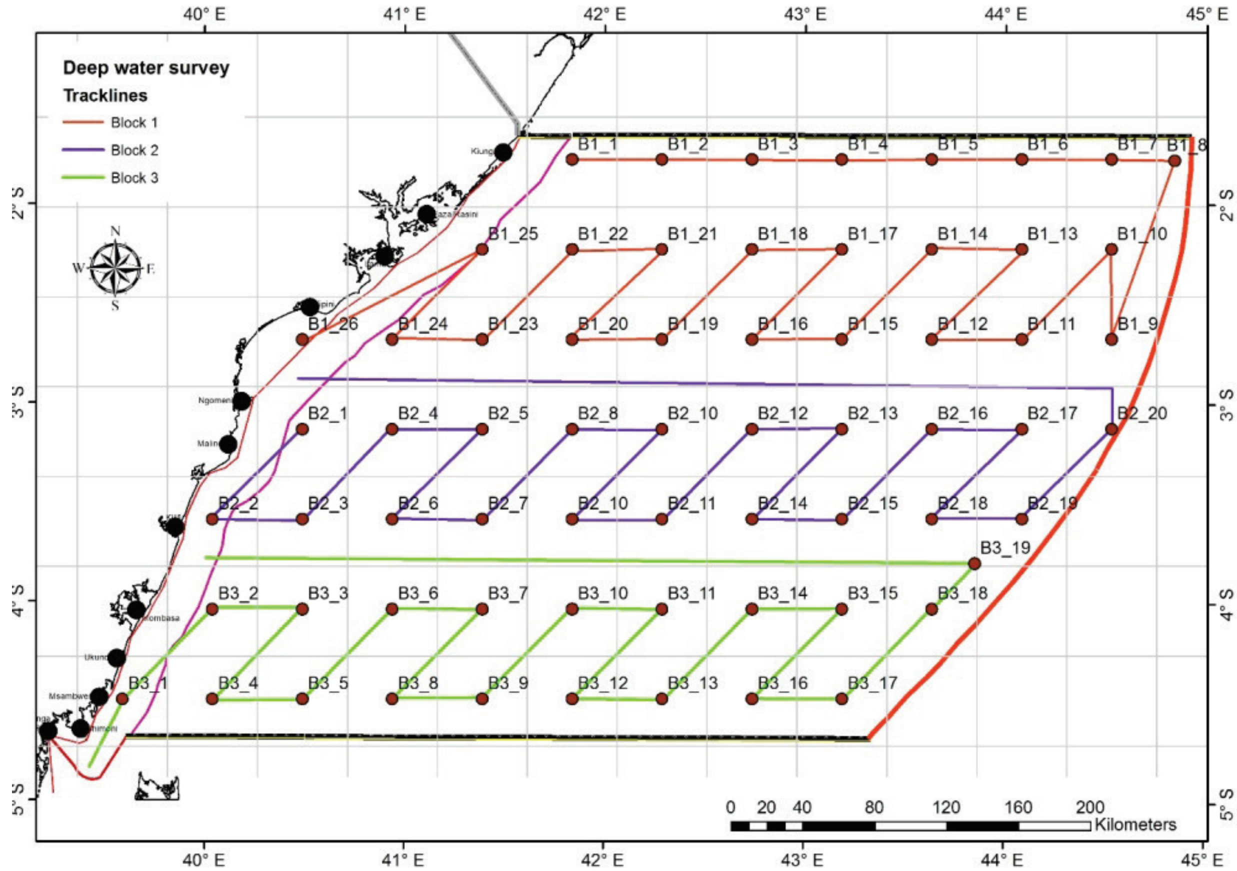

Figure 5.1.2: RV Mtafiti scheduled EEZ survey transects, sampling stations during 2016-2017

5.1.3 Hydroacoustic data collection

RV Mtafiti provides a new opportunity to better explore the spatial dynamics of fish distribution and estimate the biomass in Kenya's territorial and EEZ waters in a less invasive and efficient manner using hydroacoustics. Hydroacoustics is the study of sound in water, and is derived from the Greek words: *hydro* meaning "water" and *acoustics* meaning "sound"). Acoustics is defined as the generation, transmission and reception of energy as vibrational sound waves.

Hydroacoustics facilitates fisheries resource mapping in relation to oceanographic and habitat variables (Simmonds and MacLennan, 2005), providing high spatial and temporal resolution (Godlewska and Jelonek, 2006). The use of acoustics is based on the sonar equation:

EL = SL – 2TL + TS

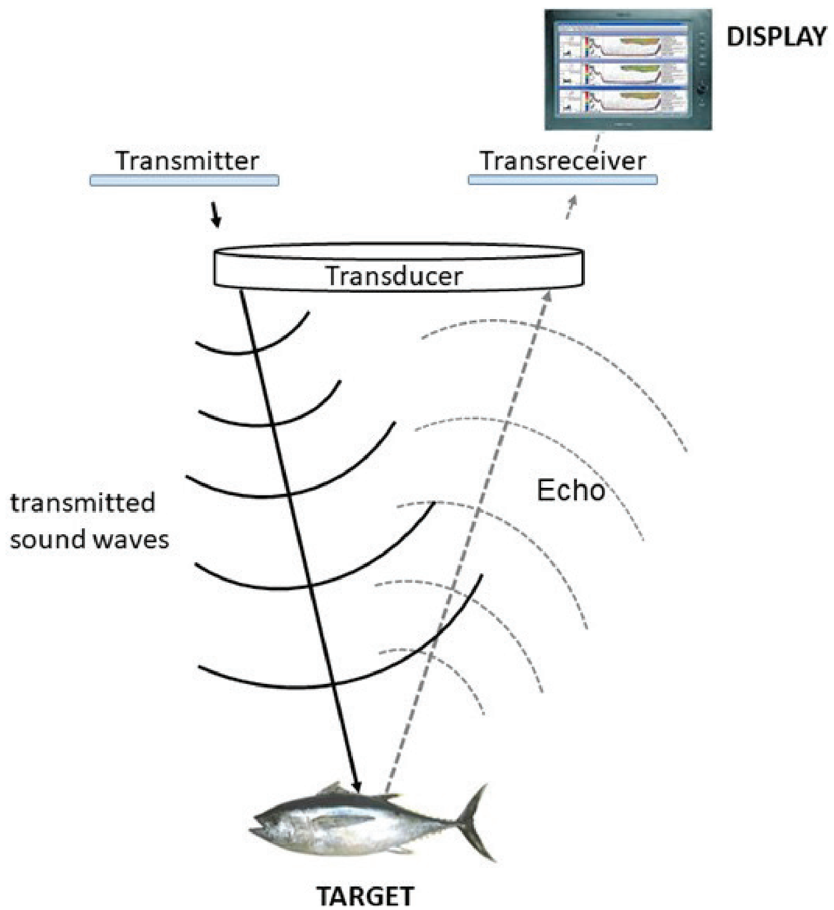

Figure 5.1.3: Schematic representation of fish detection using an echo sounder (Adapted from: Sunardi et al., 2009)

Where, EL= Echo Level, SL = Source Level (at the transducer), TL = Transmission Loss (due to geometrical spreading and absorption and multiplied by two to cater for the two-way travel time) and TS = Target Strength (of sea bottom or Fish). A measure of the total backscattering of echo signals (or echo integration, EI) from a target is used to estimate the number of fish detected (Fig. 5.1.3).

Hydroacoustic data collected onboard RV Mtafiti is taken using the Simrad EK60 scientific split-beam multi-frequency echo sounder on board the vessel throughout the survey. Fish identification and sea bottom detection is obtained by analyzing the strength of the echo received from a target. The target strengths for the Kenyan marine fishes have not yet been determined to allow for accurate biomass allocation. Target strength vary with fish size, species and depth.

A rough estimate of target strengths is described using the three equations:

TS = 20 logL (cm) - 67.4 (physoclist)

TS = 20 logL (cm) - 71.9 (physostome)

TS = 20 logL (cm) - 87.5 (no swimbladder)

Where, TS = Target strength and L = Length of fish (from Length-Weight Relationship equation Wt = aLb)

5.1.4 Bathymetry data collection

Single beam bathymetry data is acquired using the Simrad EK60 scientific split-beam multi-frequency echo sounder. The instrument operates at a frequency range of 18 to 200 kHz, at 4 ms^{-1} transmitting a pulse length to acquire water column backscatter and bathymetry data. Raw data collected in *.RAW format, is parsed with the Echo View software, in which data is corrected for changing sound velocities in the water column and noise. All individual lines are further scrutinized and corrected while adjacent overlapping lines and examined to identify vertical offsets and data gaps. From the corrected data, bottom detection techniques within the Echo View software is used to extract bathymetry from the sounder detected bottom. Further processing, mapping and visualization are completed using Quantum GIS and GRASS with ENVIZ, in which interpolation analysis is applied to generate a representative bathymetry model. It is then contoured with a geographic projection and WGS84 datum.

5.1.5 Nutrients and physicochemical parameters

Vertical water samples are collected at 20m interval using an Echman sampler. Physicochemical parameters including dissolved oxygen, salinity and pH are measured insitu using a YSI probe meter while temperature, salinity and pH are continuously recorded using a thermo-salinograph. Dissolved oxygen is determined using the Winkler method, Particulate Organic Carbon (POC) and Chlorophyll samples are filtered on board and preserved in sampling bottles for further laboratory analysis. Nutrient samples are analysed in the laboratory using a four channel auto-analyser, POC samples are analysed through the chromic acid method, and chlorophyll samples were analysed by spectrophotometric method after acetone extraction.

5.1.6 Sampling for primary and secondary productivity

Zooplankton samples are collected by towing horizontally a Bongo net of 500 μm mesh size fastened with a General Oceanic flow-meter on the mouth of the net. Deployment of the net is usually done on the side of the vessel using a winch (Plate

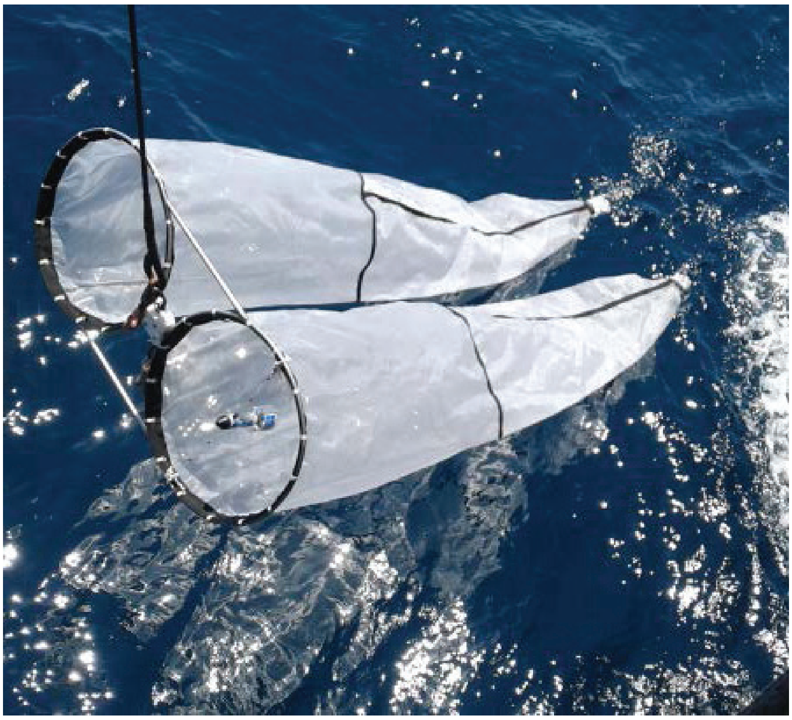

Plate 5.1.1: Zooplankton towing using twin Bongo nets onboard RV Mtafiti

Plate 5.1.2: Sieving of surface phytoplankton using a 20 litre bucket

5.1.1). Towing is conducted at constant speed of between 0.5-1.8 knots for a period of about 20 minutes. After towing, the net is retrieved and flushed with seawater into a container to collect the plankton at the bottom of the net. Fish larvae samples are extracted and stored separately in vials filled with alcohol. The larvae samples are then sorted into respective families, and identified to species where possible and counted.

Phytoplankton samples are collected from the surface waters (5m) after collection of zooplankton samples. Twenty litres of the water is poured into a bucket and sieved through 20µm mesh-size plankton net (Plate 5.1.2). The sieved material is then concentrated to 100 ml, and the samples are preserved using 5% formaldehyde buffered in seawater and labelled for storage. In the laboratory, the samples are subsampled, identified to species if possible, and counted under a stereo microscope.

5.1.7 Benthic sampling

Benthic sampling involves the collection of sediment samples only in the shallow shore stations due to a limitation in the sampling gear. Benthic samples (both sediment cores and benthos) are obtained using a Van Veen Grab Sampler attached to a winch on the side of the vessel (Plate 5.1.3). After verification of the bottom depth and contours, the grab is lowered using a graduated rope to the bottom of the seabed.

The collected sample is hauled to the surface using the winch. At the surface, benthic infauna is collected by coring using large (6.4 cm diameter) and small cores (3.4 cm) to a depth of about 10 cm of the collected sediment. The cored samples are sieved with a 0.5mm mesh sieve and the animals retained on the sieve are immediately fixed in 5% formalin and placed in labelled sample bottles for laboratory analysis. Replicate sediment cores for grain size and chemical analysis are collected labelled, and frozen for further analysis. The sediment samples are analysed for nutrients, grain size and organic matter. The samples for grain size analysis are wet fractionated except the top 2cm segment which are then dry fractionated and the clay fraction is analysed for nutrients. Thereafter, samples for nutrient analysis are extracted using KCl and analysed for nitrates, ammonia, phosphates and silicates.

Plate 5.1.3: Sampling of benthos using a Van-Veen grab sampler attached to a winch

5.1.8 Marine megafauna observations

During the surveys at least two observers are tasked to record sightings of marine mammals and seabirds using a binoculars and a spotting telescope. The observers record the species, number, location and activity, of each sighting during the day time throughout the cruise. The data is filled in a standard data collection form and projected in maps to determine their distribution.

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5.2 Physical and chemical oceanography

Charles Magori, Joseph Kamau and Shaaban Mwachireya

5.2.1 Introduction

Physical oceanography focuses on the description and understanding of the evolving patterns of ocean circulation and fluid motion, along with the distribution of its properties such as temperature, salinity and the concentration of dissolved chemical elements and gases. This information is necessary for a better understanding of the biological, chemical and physical processes taking place in the ocean. It has important applications on global climate change and coastal studies. It is also a key element in interdisciplinary studies of primary production, oceanic flux and storage of carbon dioxide.

Offshore current systems

The offshore current system off the Kenya coast is part of an alternating cycle of the Southeast monsoon (SEM) and Northeast monsoon (NEM) and is characterized by the seasonally reversing Somali Current (SC) flowing at 2 Knots, and the northward flowing East African Coastal Current (EACC) flowing at 4 Knots. The currents are dominated by the interaction between the Southern Equatorial Current (SEC) and the African coastline. The EACC is formed by the north-ward deflection of the SEC when it hits the African mainland in southern Tanzania and northern Mozambique (Fig 5.2.1).

The EACC flows northwards throughout the year, accelerated during the SEM when reinforced by the prevailing winds to speeds of 0.5-0.75 ms^{-1}, and slower during the NEM when the monsoon winds

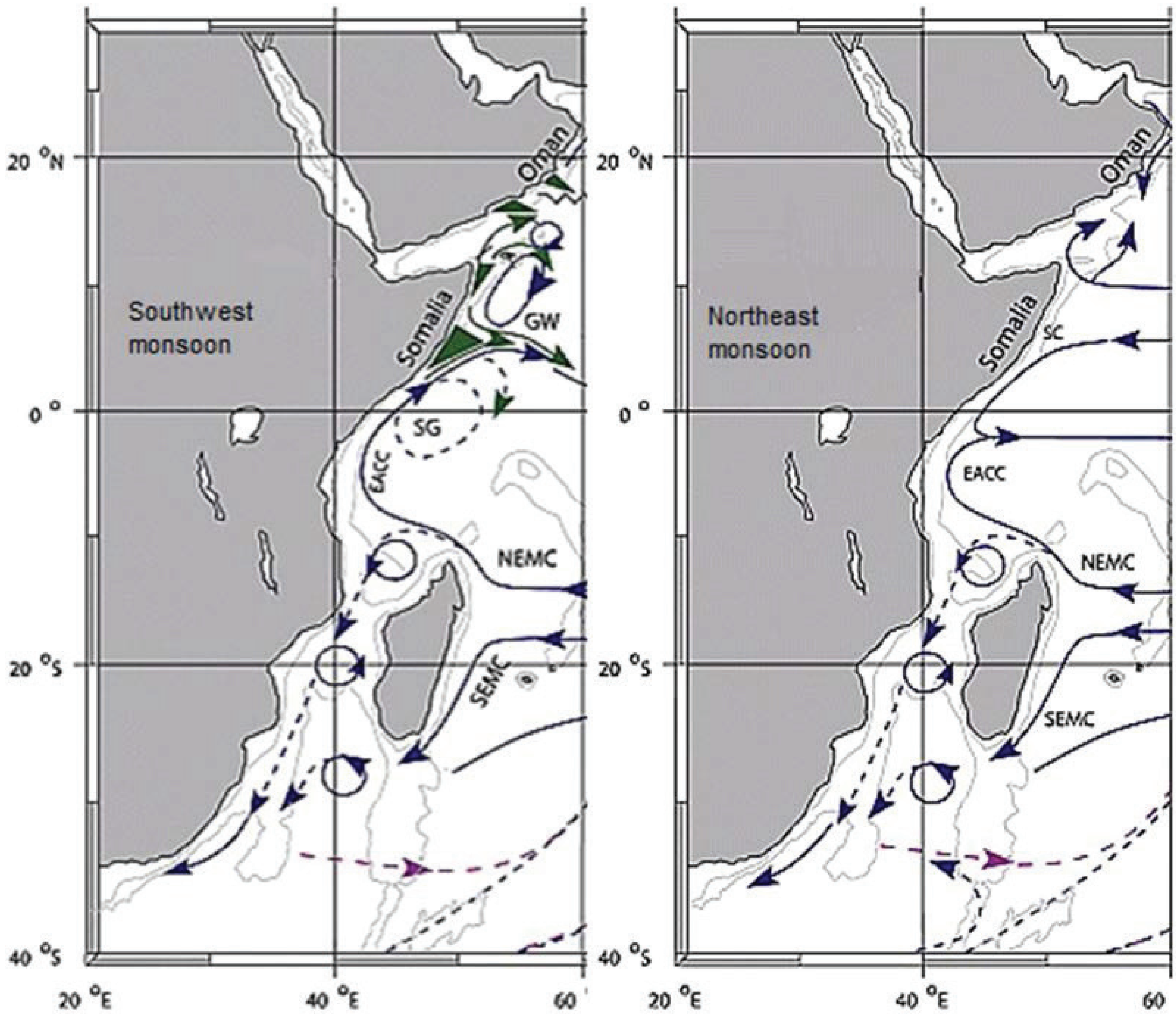


Figure 5.2.1: Schematic representation of identified current branches during the southwest and northeast monsoon in the WIO region. Current branches shown include the South Equatorial Current (SEC), South Equatorial Counter Current (SECC), Northeast and Southeast Madagascar Current (NEMC and SEMC), East African Coastal Current (EACC), Somali Current (SC), Southern Gyre (SG) and Great Whirl (GW), Southwest and Northeast Monsoon Currents (SEMC and NEMC) (Adapted from Schott et al., 2009)

blow counter to the current, at speeds of < 0.25 ms^{-1} (Obura *et al*., 2002). During the NEM, the (SC) flows southward at a speed of 1.5-2 ms^{-1}. The reversed SC meets the EACC at latitude 2.25°S to form the eastward flowing Equatorial Counter Current (ECC) which flows as an undercurrent (Düing and Schott 1978, Johnson *et al*. 1982). The width of EACC is 160-200km with its maximum depth at about 400m. It has an annual mean velocity of about 0.8ms^{-1} and its volume flux is of the order 19.8-4.8Sv (Swallow *et al*., 1983, Schott and McCreary, 2001).

The Monsoon Winds

The influence of the monsoon winds in the Kenya coast peaks between December and March (NEM) and May-October (SEM) with 1-2 months transition periods in between characterized by variable and lower winds (Fig. 5.2.1). Secondary in influence to the monsoon winds, the northern Kenya coast is bathed seasonally by the SC system, receiving cold upwelling waters pushed southwards during the NEM. There is generally a strong variation in the physicochemical parameters driven by monsoon winds.

Ocean Temperature

Ocean surface temperature in the Kenyan EEZ shows typical variations that can be attributed to the influence of the coastal current system and the monsoon seasons (Nguli, 2006). Climatologically, temperatures have been ranging between 25°C and 31°C with lows being registered during the SEM. During the SEM, the temperatures are generally lower ranging between 24.5°C and 25.8°C (Nguli, 2006). The lowest temperatures occur during the months of July and August as a result of the influence of the EACC which brings relatively cool water from the south (Newell, 1959, Nguli, 2006). In the open offshore waters, sea surface temperatures are relatively higher, in the shallow inshore areas, with temperatures exceeding 30°C in the NEM.

There are two temperature maxima corresponding to the transition periods between the monsoon seasons when winds are light and variable and insolation is high. The first maximum occurs at the end of the SEM in October/November when water temperatures can rise to 30°C. The second maximum occurs at the end of the NEM in March/April when insolation is highest. During the El Nino of 1994-1998 the temperatures exceeded normal level by up to 2^0C (Mdodo, 1999). The thermocline characterized by the largest vertical gradient occurs at a depth of 120m in August and March, and 80m in June and December. This vertical variation is due to the large seasonal variations in current velocities and the seasonal confluence of the EACC and the SC (Swallow *et al*. 1991).

Tidal patterns

The tidal patterns of the Kenyan coast have semi diurnal periodicity with a spring range of up to 4m and neap range of about 1.8m. The lowest tides of about 1m occur during the northeast monsoon with 80% of the swells reaching maximum significant height of 6m. Flows of inshore waters are strongly influenced by tidal flushing patterns. The sea is usually calm during the inter-monsoon period (March-April) and wave height drops significantly to 2.5m and shifts clockwise to a southerly approach with large fluctuations in direction. During the SEM, waves are usually very large with a maximum significant height of up to 8m. These usually approach the coast predominantly from south-east and southwest direction. In the inter-monsoon period, calm conditions prevail and waves tend to approach the coast from a north-east direction.

Sea level change

Sea level rise is a real phenomenon and the two major causes are thermal expansion caused by warming of the ocean (since water expands as it warms) and increased melting of land-based ice, such as glaciers and ice sheets. To date oceans are absorbing more than 90 percent of the increased atmospheric heat associated with emissions from human induced activity. The inter-annual variation in sea level has been attributed to thermal expansion of the ocean due to global warming. Global sea level has been rising over the past century, and the rate has increased in recent decades. According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), global sea level was 2.6inches above the 1993 average, the highest annual average in the satellite record (1993 - present). Sea level continues to rise at a rate of about one-eighth of an inch per year.

KMFRI, as a member of the Global Sea Level Observing System (GLOSS) established by the UNESCO Intergovernmental Oceanographic

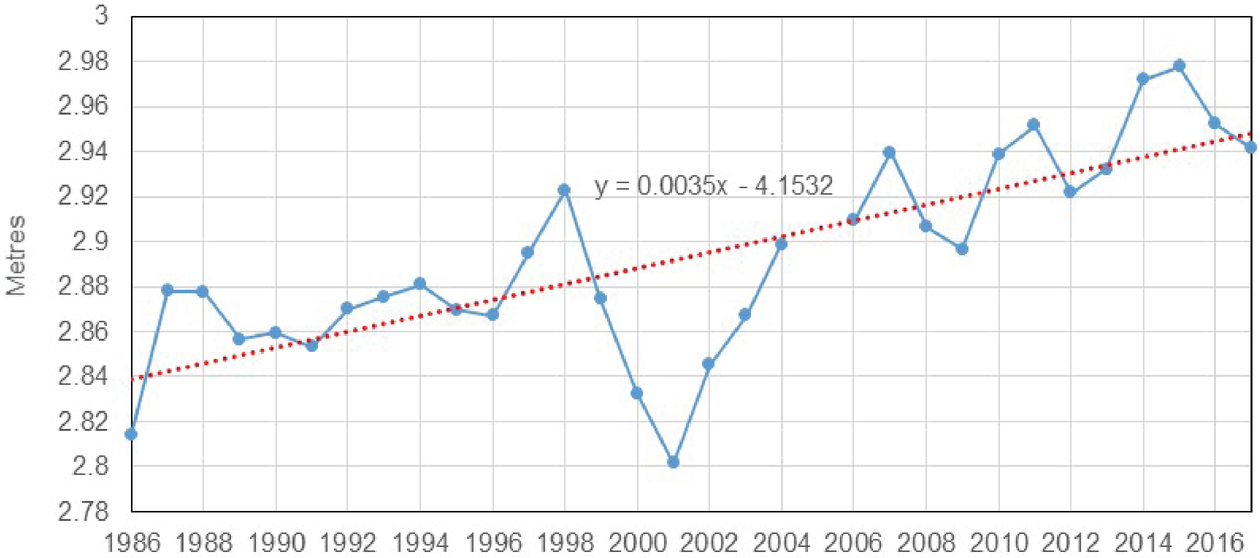


Figure 5.2.2: Mean annual sea level variation recorded by the KMFRI tide gauge in Mombasa (Source: UHSLC)

Commission (IOC) in 1985, has been collecting high-quality in situ sea level data since 1986. The mean annual variation in sea level data recorded by KMFRI at the Mombasa tide gauge station reveals an increasing trend of sea level of about 2mm per year (Fig. 5.2.2), consistent with global trends as reported by the National Aeronautical and Space Agency (NASA) which indicate that the rate of global mean sea level change is currently at 3.2mm per year with a margin: ±0.4 and the ocean mass is increasing by $1.8mmyear^{-1}$ at a margin of ±0.3. Sea level rise at specific locations may be more or less than the global average due to many local factors: subsidence, upstream flood control, erosion, regional ocean currents, variations in land height etc.

Ocean Acidification

The burning of fossil fuels and other human activities has been implicated in increased emission of carbon dioxide (CO_2) into the atmosphere and the release of about 1.6Mt trillion of CO_2 (Siegenthaler *et al*., 2005). A third of this CO_2 is absorbed by the world oceans resulting in changes in seawater carbon chemistry (increase in $[CO_2]$ aq and $[HCO_3^{-1}]$, decrease in carbonate saturation state (Ω) and $[CO_3^{-2}]$) as well as lowering of ocean pH (Rhein *et al*., 2013) causing acidification of ocean waters (Fig 5.2.3). If the current trend in the use of fossil fuels continues, ocean pH will likely drop further by the end of the 21st Century and increase ocean hydrogen ion concentration (ocean acidification) by more than 100% relative to preindustrial times. Ocean acidification has many direct and indirect implications on the global and regional oceans, marine ecosystems, processes and organisms, especially those organisms that physiologically rely on the delicate balance of dissolved inorganic carbon.

Despite the potential impacts of ocean acidification on marine ecosystems, habitat and societies, very few studies on the subject have been undertaken in the East African region (Hilmi *et al*., 2013). However, Sumaila *et al*., (2011) has highlighted the potential direct impacts of acidification including the negative effects on artisanal fisheries

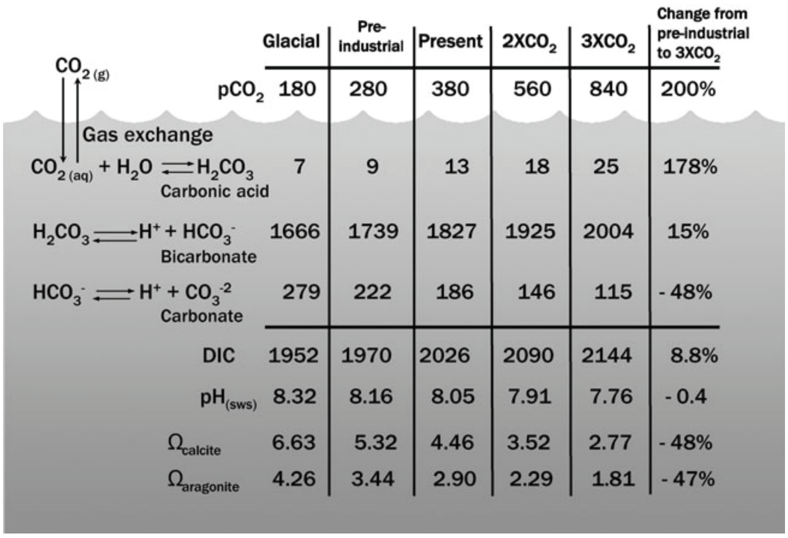


Figure 5.2.3: Concentrations of carbon species ($\mu molKg^{-1}$), pH values, and aragonite and calcite saturation states of average surface seawater for pCO_2 concentrations (ppmv) during glacial, preindustrial, present day, two times pre-industrial CO_2, and three, times pre-industrial CO_2 (Fabry et al., 2008)

and molluscan mariculture (abalone, oysters and scallops). Other impacts include reduction in reef fisheries, recreation and tourism and the associated livelihoods and economic benefits, coastal protection, food security including pelagic fisheries, particularly tuna. Furthermore, increased stratification of the water column resulting in nutrient limitation and decreasing productivity and deoxygenation as a result of acidification are predicted to occur (Gruber 2011). Ultimately, exacerbates poverty, public health and food insecurity and more ecosystem degradation and compromised national economies. Overall, ocean acidification threatens the resilience, productivity, function and ecosystem services provided by critical marine and coastal ecosystems.

Current ocean acidification predictive models assume that nearshore reef waters acidify at the same rate as oceanic waters, however, nearshore reef water carbon chemistry exhibit tidal cycle, spatial, temporal as well as diurnal variations (Bates *et al*., 2001). Further, CO_2 and ocean acidification are not uniformly distributed globally but exhibit hotspots culminating in variable impacts spatially as well on ecosystems and organisms. Nevertheless, the global current system acts as conveyor belts distributing dissolved CO_2 throughout the global oceans thereby impacting many ecosystems and organisms worldwide. A number of organisms such as corals, shellfish, pteropods, coccolithophores, echinoderms and squids have been shown to be highly vulnerable to acidification, while organisms such as jellyfish (Winanas and Purcell, 2010), algae (Connell and Russell 2010) and seagrasses (Hall-Spencer *et al.*, 2008) have been reported to benefit from increased acidity. Ocean acidification will also have negative impacts on lower trophic levels (Kroeker *et al.*, 2011) such as plankton and energy transfer to higher trophic levels accompanied by shifts towards detritus based food webs (Ullah *et al.*, 2018) that will unlikely support current biodiversity and ecosystems. Additionally, ocean acidification will also modify predator-prey interactions, prevalence of invasive species, changes in pathogen distributions as well as algae-grazer interactions. The livelihoods of coastal communities in Kenya are inextricably linked to the quality, health and function of coastal and marine resources through the provision of coastal protection, employment and food security. Projected increases in atmospheric CO_2, its dissolution in the ocean and interaction with local disturbances will likely have profound consequences on marine ecosystems, organisms, processes and human populations.

Ocean Salinity

Salinity makes an important contribution to ocean dynamics and thermodynamics (Rao and Sivakumar, 2003). Salinity patterns off the Kenyan coast are influenced by the outflow of low-salinity water from the Bay of Bengal (Newell, 1959) and by the Indian Ocean Dipole (IOD) (Vinayachandran and Nanjundiah, 2009). The high salinity water originates from the Arabian Sea and Red Sea. Low salinity occurs in the bays and creeks where the influence of river runoff is greatest. During the inter-monsoon periods (May-April), the offshore waters are usually characterized by relatively low surface salinity ranging between 34.74 and 35.08 PSU. This is attributed to rainfall as well as flow of relatively low salinity water from the Bay of Bengal and Indonesia (Newell, 1959).

The surface salinity in the Indian Ocean ranges from 32 to 37 parts per 1000 and varies with depth. As the depth increases the salinity also increases. In the offshore waters, salinity increases with depth to reach a maximum value of 35.5 PSU near the thermocline (80-120m) (Nguli, 2006) and then decreases with depth to a steady value of 34.9 PSU. Minimum salinity values are associated with heavy rainfall especially nearshore (32-33 PSU). During the *El Nino* in 1997-98, shallow reef areas experienced larger decreases in salinity due to heavy rainfall, down to 12 PSU (Mdodo, 1999).

Upwelling and Vertical Mixing

The northward and southward flow of the monsoonal and local winds drive the surface flows off the Kenyan coast causing localized upwelling. The alongshore stress of the equator-ward winds induces an acceleration of the surface currents, which drift offshore under the influence of the Coriolis force. Johnson *et al.*, (1982) postulate that the deflection of the EACC seaward at its point of convergence with the SC is mainly due to topographic forcing in the North Kenyan Bank. The SW monsoonal upwelling to the north of the Kenya coast is mainly geostrophic and is caused by the tilt in the thermal structure as the current swings away

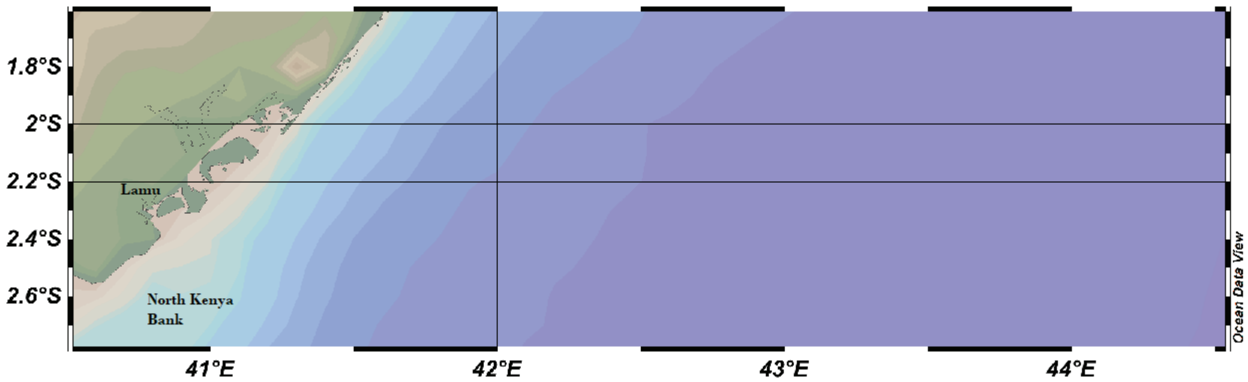


Figure 5.2.4: Map showing the depth transect of analysis shown in Figure 5.2.5

from the horn of Africa. The rapid northward flow of water during the SE monsoon, aided by the strong winds, causes vertical mixing of the water mass so that the EACC has similar physical and chemical properties throughout its depth to the boundary with the underlying water mass.

5.2.2. RV Mtafiti biogeochemical observations

RV Mtafiti cruises conducted in 2016/17 enabled KMFRI to map out the most current situation of the EEZ in terms of biogeochemistry and nutrients dynamics. The physicochemical parameters temperature (Temp), dissolved oxygen (DO), chlorophyll-a (chll-a), particulate organic carbon (POC), silicates (Si), upwelled silicate signature denoted as (Si*) (the difference between available silicate ($Si(OH)^4$, and nitrates (NO^3)), and Phosphates (PO^4) were measured from the surface to 600 m deep, spanning between 1.8°S to 2.5°S and 40.5°E to 44.5°E (Fig. 5.2.4). Higher biogeochemical activity was observed in the sections between 44°E and 44.5°E, and between 42°E and 43°E which had high POC, Si and NO^3 associated with higher chll-a, and DO, indicating areas of high productivity. (Figure 5.2.4 & Figure 5.2.5 A & B)

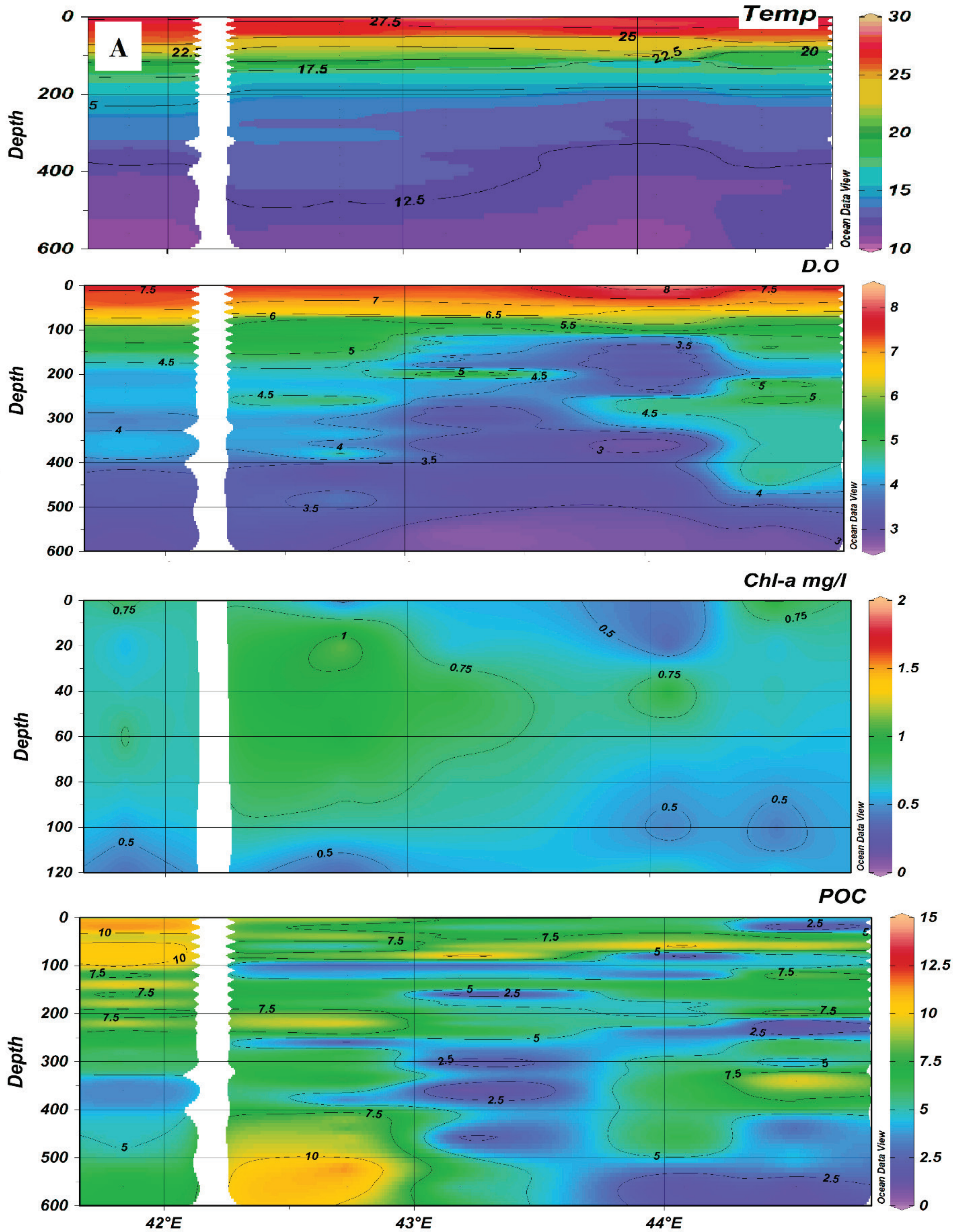
Primary productivity and respiration vary widely across different ecosystems and are indicators of ecosystem trophic conditions. If primary productivity exceeds respiration, then the system is autotrophic and internal production of organic matter dominates. When respiration exceeds primary productivity, the system is heterotrophic and relies on an outside source of organic matter (Mitsch and Kaltenborn, 1980; Caffrey, 2003). In the case of Kenya's EEZ, higher respiration was observed around the section between 44°E and 44.5°E which exceeded primary productivity (considering chlorophyll-a as a proxy). Thus, it can be deduced that the system relies on an outside source of organic matter. The distribution trend of Si*, used as a proxy for upwelling, further corroborates this observation (Figure 5.2.5 A & B).

Si concentration is considered an important indicator of nutrient availability, especially in relation to the requirements of diatoms (Ragueneau *et al.*, 2000; Brzezinski *et al.*, 2003). Diatoms accumulate biomass with a silicate and nitrate molar ratio of 1:1 when sufficient light and nutrients (including iron) is available (Brzezinski *et al.*, 2003). The enhanced Si concentration in relation to NO^{-3} indicates that the mineralized matter is not purely from the surrounding biota. Therefore, it can be deduced that the section between 44°E and 45°E, and between 42°E and 43°E is mainly associated with upwelled waters.

Higher nitrate levels were observed in the deeper waters (Fig. 5.2.5 B), and depleted levels in the surface waters. In most ocean waters, nitrate levels are depleted at the surface waters through consumption by phytoplankton, and increase with depth exhibiting a strong vertical gradient or nitracline. A positive correlation between POC and NO^3 was also observed indicating that the source of NO^3 in the area is through decomposition of biogenic organic matter. However, the elevated Si* levels also indicate another source. The vertical supply of nutrients to the surface euphotic zone is influenced by the vertical gradient (slope) of the nitracline and by the vertical separation (depth) of the nitracline from the sunlit surface layer.

Surface dissolved oxygen and temperature

There was an inverse relationship between DO and temperature, with cooler temperatures at the surface waters generally corresponding with high DO levels. The distribution of dissolved oxygen (DO) and temperature in the surface waters is presented in Fig. 5.2.6. The areas between 3.5°S and 4°S and


A
Temp
D.O
Chl-a mg/l
POC
Depth
42°E
43°E
44°E
Ocean Data View

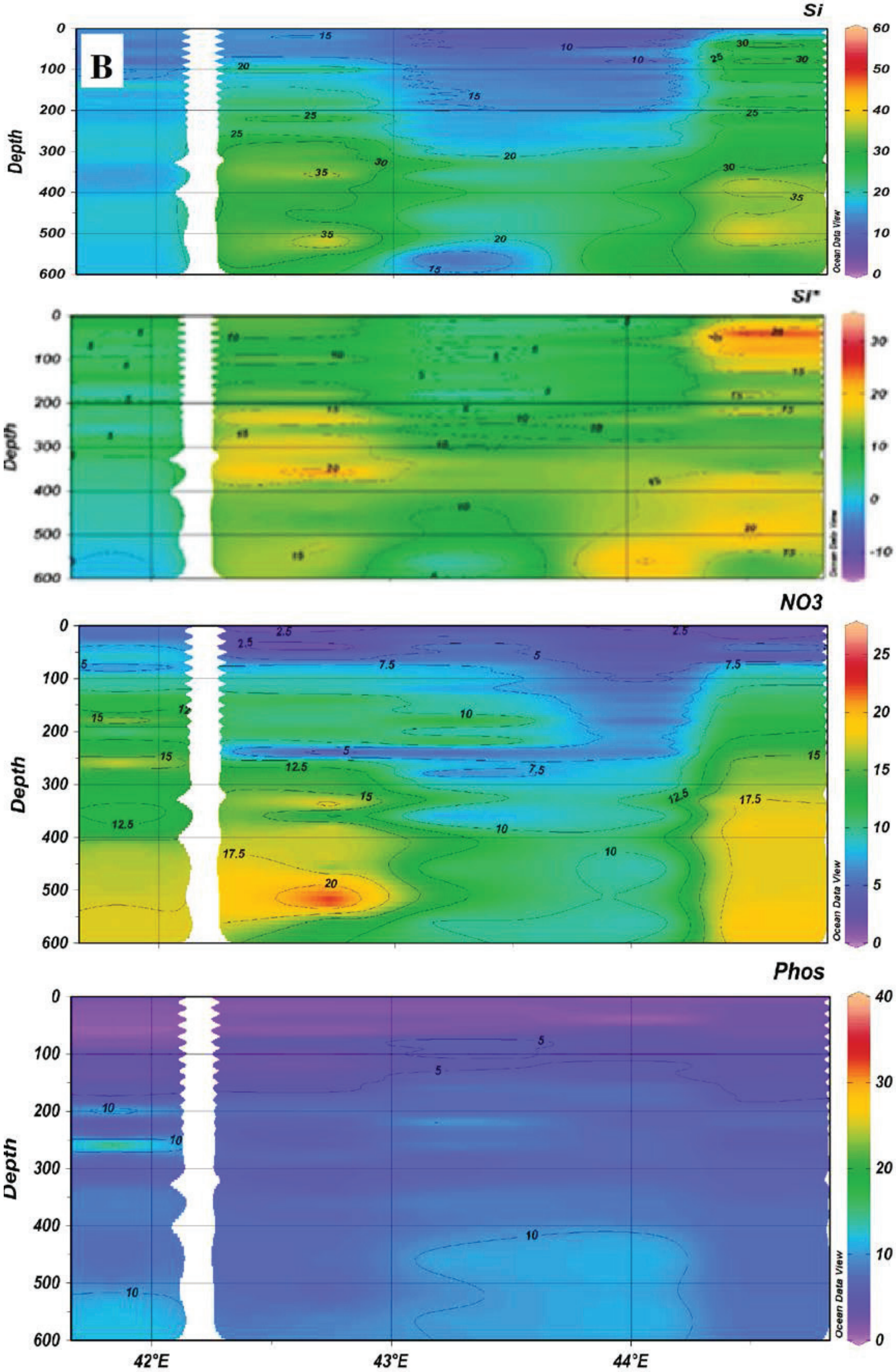


Figure 5.2.5: A & B. Northern EEZ water column vertical profiles showing (a) Distribution of the parameters Temperature (0C); Dissolved Oxygen (moles l^{-1}); Chl-a (mg l^{-1}); POC (mg l^{-1}) and (b) Nutrients concentration (mg l^{-1}) recorded during RV Mtafiti cruises in 2016/2017

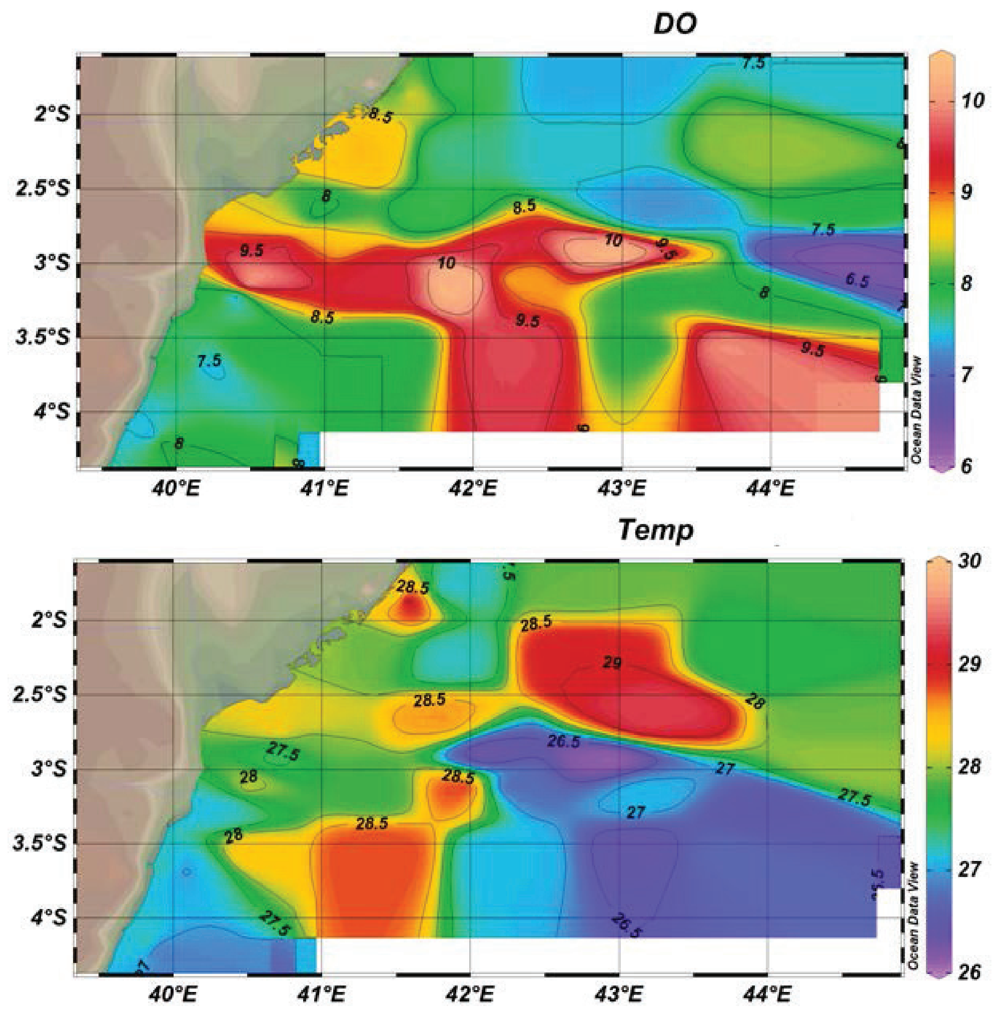


Figure 5.2.6: The distribution of surface dissolved oxygen (DOmg l^{-1}) and temperature (Temp°C) in the Kenya EEZ recorded during RV Mtafiti 2016/2017 cruises

between 42°E and 45°E registered low temperature and high DO fronts, indicative of cool dense waters flow from the bottom to the surface. The spatial plots of temperature and DO suggest the presence of an upwelling emanating from 3°S, 43°E and moving westwards and veering southwards. This may be associated with the ECC that forms during the NEM when the Somali Current reverses and flows southwards. The convergence seems to occur around the 3°S latitude and the ECC veers southwards as it heads eastward.

Nitrates and phosphates

Primary production is limited by the supply of nutrients, especially nitrates and phosphates to the euphotic layer. The distribution of nutrients in the ocean is mainly controlled by biogeochemical processes that include the production and decomposition of biogenic organic matter and sinking of particulate matter. Nutrient enrichment due to decomposition of plankton and biota material is assumed to constitute a 1:1 ratio of Si to nitrates. The transport of dissolved organic matter (DOC) controls the vertical distribution of nutrients (Takahashi *et al*., 1985; Anderson and Sarmiento, 1994; Banse, 1994). Inorganic nitrogen can also be a limiting factor controlling primary production in subtropical and tropical oceans (Capone *et. al*., 1997). Consequently, a major part of primary production is supported by upwelling of deep waters rich in nitrates and phosphates.

The surveyed area corresponding to the north Kenya banks (2.5°S and 2.8°S, and between 40.5°E and 41.5°E) was associated with high phosphate levels (Fig. 5.2.7). Similarly, the sections between 3°S and 3.5°S as well as 44°E and 45°E had high concentrations. Among the key nutrients, i.e. nitrate, phosphate and silicate, inorganic phosphorus is traditionally considered to be a basic limiting factor for oceanic primary production, since nitrogen can be delivered via nitrogen fixation by bacteria under aerobic conditions (Broecker and Peng, 1982).

Surface enhanced silicate (Si*) and chlorophyll-a

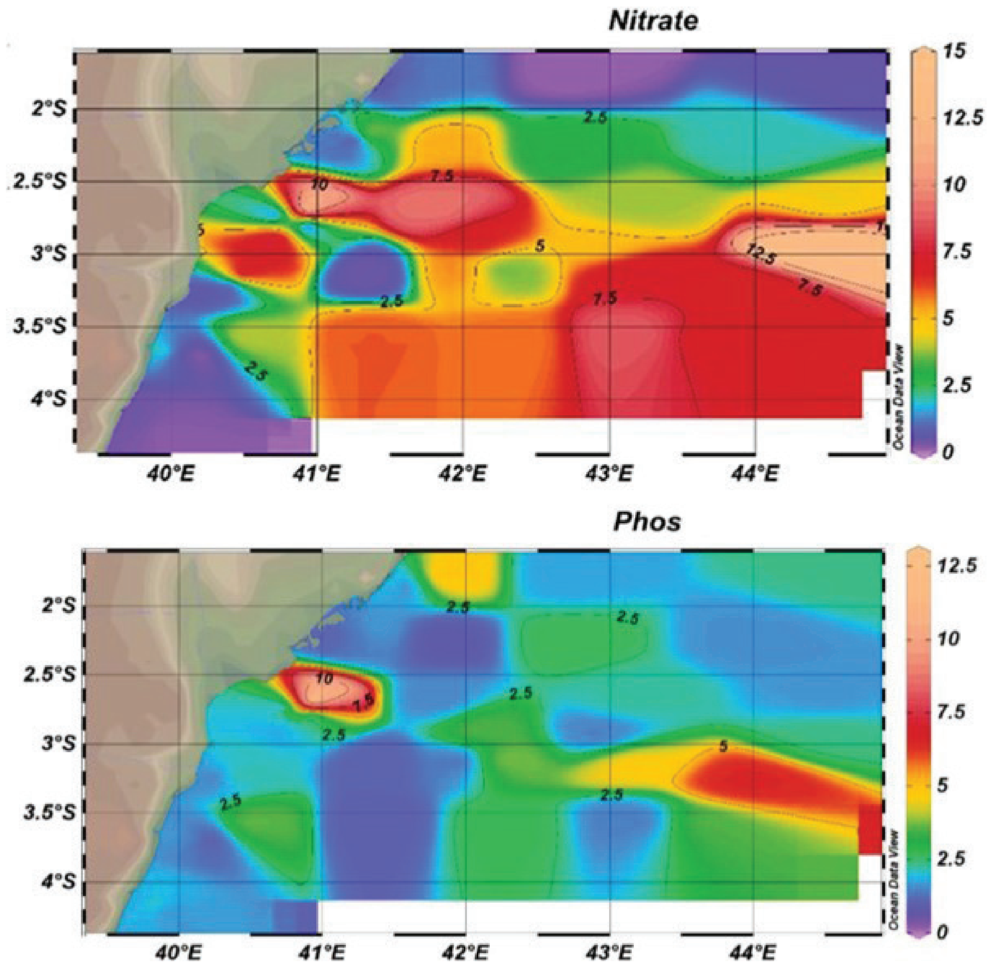


*Figure 5.2.6: The surface distribution of nitrate and phosphate concentration in the Kenya EEZ recorded during RV Mtafiti 2016/2017 cruises * concentration in mole l^{-1}*

The productivity of a marine system is also indicated by the presence of chlorophyll associated with enhanced nutrients levels. Sarmiento *et al*., (2004) used Si* as a tracer of the return path of deep waters up-welled in the Southern Ocean into the thermoclines of 22 ocean systems. The observed spatial distribution of Si* and Chll-a within the surveyed areas indicates an upwelling region around the sections spanning 43.5°E and 45°E, and between 3°S and 3.5°S, corresponding with high nitrate levels (Fig. 5.2.7). The Chll-a levels were significantly higher south of 2.5°S indicative of high productivity. Global Chll-a levels mainly range between 0.02 and 3mgm^{-3} compared to the maximum recorded during the survey of 1 mgm^{-3}. The observed Si* and chlorophyll-a spatial distribution further corroborates with the deductions previously made on the physicochemical parameters indicating areas of upwelling.

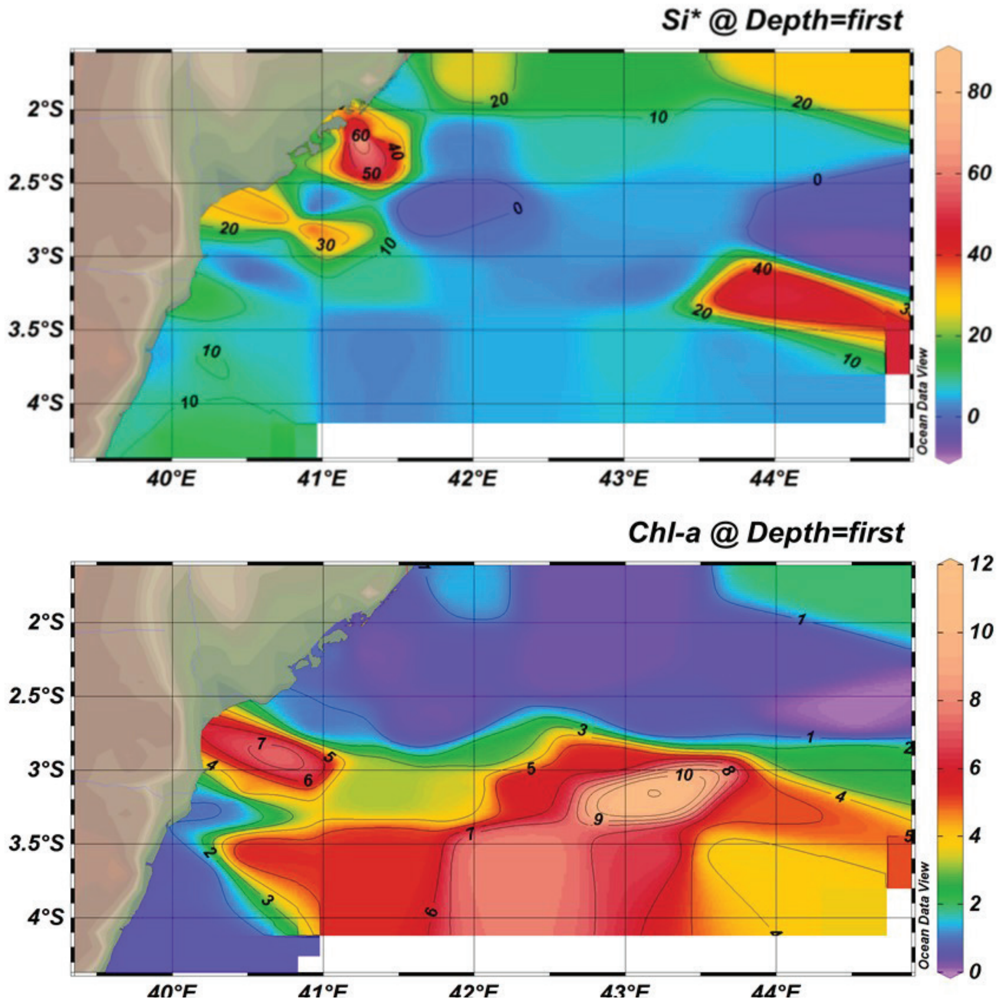


Figure 5.2.7: Surface enhanced silicate (Si) and chlorophyll-a distribution within the Kenya EEZ recorded during RV Mtafiti 2016/2017 cruises*

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5.3 Marine Geomorphology and Sedimentology

Amon Kimeli and Amina Makori

5.3.1 Introduction

The Indian Ocean is a veritable storehouse of diverse and complex tectonic features (Gupta and Desa, 2001). However, it is the least studied and explored compared to the other oceans despite evidence of substantive maritime activity in the modern era. Bathymetry is the representation of water depths and shapes of underwater features otherwise referred to as the geomorphology or ocean topography. Bathymetric data are increasingly a vital requisite for a broad variety of geological, geophysical and oceanographic analyses and modelling (NOAA, 2018; Jakobsson *et. al.*, 2008).

Bathymetric datasets have become more useful in understanding the effects of climate change on the marine environment, particularly in gaining insights to ongoing and potential beach erosion, sea-level rise, and subsidence (land sinking). The data is also vital in the creation of hydrodynamic models e.g. tsunami run-up models and updating navigational charts with new or relevant information. Finally, it is also essential in understanding and demarcating fishing grounds and identification of trawlable seabed areas. Multibeam Sonar (MBES) and Single Beam Sonar (SBES) systems have been widely used in bathymetric mapping (Parnum, *et. al.*, 2009). This chapter provides an overview of the bathymetry and seabed morphology of Kenya's territorial waters and the EEZ form the surveys conducted onboard the RV Mtafiti.

5.3.2 Historical surveys

Kenya has participated in some historical deep sea cruises through which vital data and information on geomorphology and sedimentology has been generated. Table 5.3.1 shows some of the past marine surveys conducted in Kenya and the wider Indian Ocean basin.

Sand is the principal sediment component in Kenya's continental shelf floor, while mud is dominant in the deeper waters (Abuodha, 1993; Hove, 1980a). In addition to extensive occurrence of bioclastic and authigenic carbonates in the Kenyan coast, River Tana and Sabaki supplies massive amounts of terrigenous sediments. Two distinct sedimentological provinces are recognized along the Kenyan coast: to the north medium to fine sands interlaced with carbonated dominate and the biogenic sands dominated south (Abuodha, 1992). In 2007, the Government of Kenya commissioned a bathymetric multibeam (MBES) survey to provide data for delineation of Kenya's Outer Continental Shelf as prescribed by UN's International Seabed Authority (Fig. 5.3.1).

Table 5.3.1 Some of the previous research cruises carried in the Indian Ocean that include the Kenya EEZ

Expedition/Cruise	Year	Data collected	References
International Indian Ocean Expedition (IIOE-1)	1959-1965	Sediment cores: • Mineralogy • Isotopes • Macro fauna Thermometric depths (bathymetry)	Udintsev, 1975
RV Ujuzi	1979-1981	Sediments: • Mineralogy • Fluxes	Hoorweg, 1998
Ocean Drilling Program	1983-2007	Drill cores: • Stratigraphy • Dating • Mineralogy • Deposition rates	Duncan et. al., 1990
RV Tyro	1993	Sediment grabs: Sediment cores: • Continental shelf topography • Sediment distribution	Abuodha, 1993 Hove, 1980a

The survey objective was mainly to determine the geomorphology and to acquire data for delineating Kenya's extended continental shelf beyond 200 nautical miles. KMFRI scientists have analysed this data further and observed interesting geomorphology with three large seamounts ranging between 800 and 1500 m (Fig. 5.3.1). This survey served as a window into little known bathymetric features that are in the Kenyan deep ocean and indicates the need for more research to be conducted in these areas.

5.3.3 Bathymetry

Data for bathymetry data taken on-board RV Mtafiti showed the classical transition from shallow continental shelf to the deep oceans. Due to the wide spacing of cruise tracks, a large grid was used to extrapolate patterns. Some geological and geomorphological features associated with the deep oceans (seamounts and deep-sea trenches) have possibly not been detected due to the large spacing between data points and the large grids used in the extrapolation. The generated bathymetry data is therefore indicative (Fig. 5.3.2).

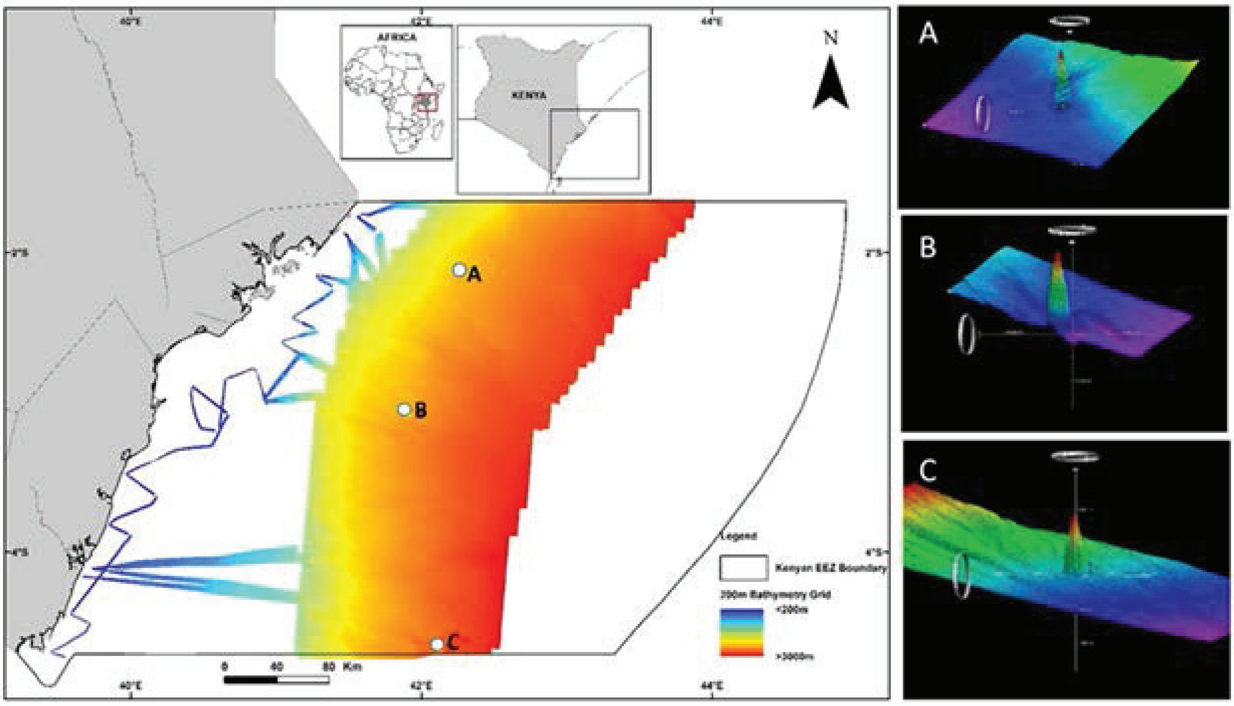


Figure 5.3.1 Outputs of a bathymetric multibeam (MBES) survey of Kenya's continental shelf area, showing the three seamount locations and their respective 3D images processed using the Fledermaus© software at the Centre for Coastal and Ocean Mapping (CCOM) of the University of New Hampshire, USA.

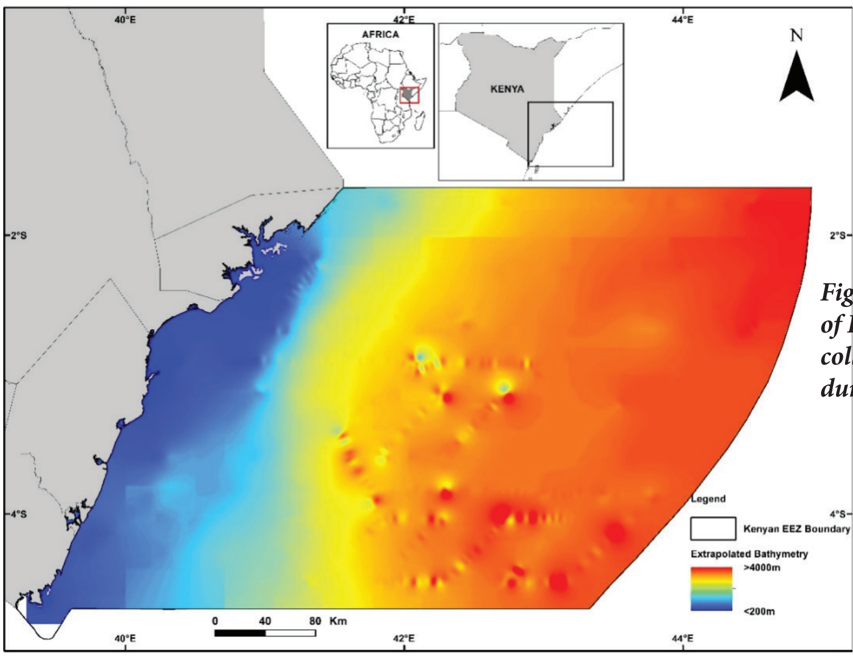
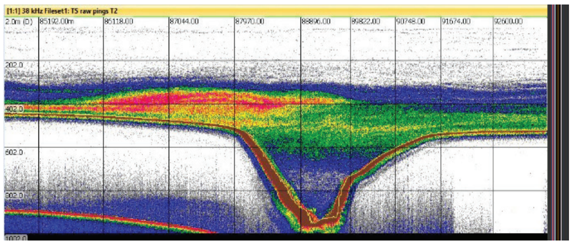
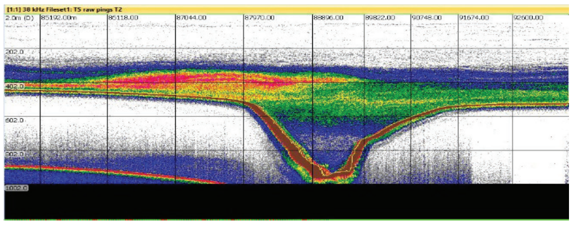


Figure 5.3.2 The bathymetry of Kenya seabed from data collected using RV Mtafiti during 2016/2017

Table 5.3.2 Selected unique geomorphologic features within the Kenyan EEZ.

Feature	Geolocation/ description	Image
Guyot/Seamount	Lat -2.670500 Long 40.456517 250m high off Kilifi.	
Deep Trench	Lat -1.886917 Long 41.545850 600m deep Off Kiunga	

5.3.4 Unique geomorphologic features

Some notable unique bathymetric features that may influence biological productivity and the use of ocean space were observed during RV Mtafiti cruises. The depths at which the geomorphological features were detected ranged from less than 200m to more than 4000m. Among them were deep trenches as deep as 500m and guyots (flat-topped seamount) as high as 250m (Fig. 5.3.2). There is therefore a need to further survey these features especially using full sea floor coverage techniques e.g. MBES to ascertain their orientation and lateral extents. This information subsequently assists in determining the processes and geological evolution of the Kenyan Ocean basin. Guyots and canyons act as biological hotspots e.g. aggregators of fish and therefore their mapping is vital for many disciplines such as geology, oceanography, biology, ecology, and possibly in harnessing of the Blue Economy (NOAA, 2018).

5.3.5 Data gaps, capacity building needs and future opportunities

Over 70% of planet earth is covered by world oceans and an estimated 80% of it remains unmapped and unexplored compared to other mapped planets in the solar system (Carron *et. al*. 2001). However, knowledge of the shape of ocean's seafloor is critical in so many aspects relating to resource exploration, exploitation and sustainable management. Kenya having recently emphasized the development and valorization of its Blue Economy, bathymetric data will play a critical role. Based on the Kenyan multibeam survey of 2007 over 50% of Kenyan EEZ remains unmapped to acceptable full seafloor coverage standards (100-metre pixel size or better). Acquisition and processing of bathymetric data is highly technological and therefore there is a need to acquire state-of-the instruments that would allow for data collection (e.g. Multibeam acoustics echo sounder). Training of enough personnel in areas of data collection and processing is equally indispensable. Acquisition of RV Mtafiti as well as participation in the second IIOE and collaboration with the Seabed 2030 initiative, provides short and long-term opportunities to continue filling gaps in mapping of the EEZ and nearshore waters to acceptable global standards.

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5.4 Primary and Secondary Productivity

James Mwaluma and *Harrison Ong'anda*

5.4.1 Introduction

Plankton is essentially a group of microorganisms consisting of plants (phytoplankton) and animals (zooplankton) that float freely in surface waters of oceans and lakes. Plankton forms the base of the marine food web, providing nourishment to higher trophic levels from squid and fish to whales and seabirds (Hugget and Kyewalyanga, 2017). They consist of diatoms, protozoans, small crustaceans, and the eggs and larval stages of larger animals. They also include bacteria (bacterioplankton) and viruses (virioplankton).

While some forms of plankton are capable of independent movement swimming hundreds of meters vertically in a single day (termed as diel vertical migration), their horizontal position is primarily determined by the surrounding water movement driven by ocean currents. This is in contrast to nekton such as fish, squid and marine mammals, which can swim against the ambient flow and control their position in the environment. Phytoplankton serve as the base of the aquatic food web as primary producers using sunlight and nutrients from the sea to produce their food, providing an essential ecological function for all aquatic life. Numerically, the most important groups of phytoplankton include cyanobacteria and algae, mainly diatoms and dinoflagellates, although many other groups of algae are also represented (Hugget and Kyewalyanga, 2017).

Plate 5.4.1: A zooplankton sample collected onboard RV Mtafiti (magnification x30)

Zooplankton are commonly described as the passively floating or weakly swimming group of organisms that drift along with water currents. Zooplankton may generally be defined by the function of their life history and size. Based on the life history definition, zooplankton may be categorised as holo- or mero- plankton (Osore *et al.*, 2003). Holoplankton such as copepods, chaetognaths, ctenophores, cladocerans etc (Plate 5.4.1) spend their entire life as members of the plankton. In contrast, meroplankton spend only part of their lives as plankton. They include fish eggs, brachyuran zoea and a large number of planktonic larvae, which as adults live on the bottom or form part of the nekton.

Zooplankton are secondary producers feeding on the phytoplankton. Mixing in the water column due to upwelling and downwelling is an important driver that affects nutrient availability and hence plankton production. The earliest zooplankton collections in the Indian Ocean date back to 1857 - 1859 during a circumglobal scientific expedition by the Austro-Hungarian naval frigate SMS Novara (Huggett and Kyewalyanga, 2017). Subsequent major collections over the next 100 years include those by the Danish RRS *Dana* between 1928 and 1930, and the British RRS *Discovery II* between 1930 and 1938. However, the most comprehensive study of the planktonic realm took place during the IIOE. Other studies include those of Indian Ocean Experiments (INDEX) in 1979, North Arabian Sea (by U.S.A and U.K) 1992-1997, and the Netherlands Indian Ocean Project of 1992 by RV Tyro which conducted several surveys off the Somali coast, and two surveys off the Kenyan coast, during which data on nutrients, chlorophyll, primary production and zooplankton biomass and species composition were collected (Baars *et al*., 1998; Heip *et al*., 1995).

Primary productivity in the Indian Ocean is documented to be particularly higher than in other oceans, with average concentrations estimated to be twice the global average (Ryther *et al*., 1966). The Indian Ocean also hosts one of the largest phytoplankton blooms among the tropical oceans. Despite its importance, productivity in the Indian Ocean remains one of the most under studied and least understood of the world's ocean basins (Hood *et al*., 2009). The productivity data generated provides new insights on drivers of fishery productivity. Additionally, understanding the composition and distribution of fish larvae will help to identify potential areas of fish breeding, especially for high value fish like the tuna.

5.4.2 Survey results

Phytoplankton abundance and diversity

In general, high primary productivity was found in the territorial waters as compared to offshore EEZ sites in both cruises. This is possibly due to higher nutrient loads from land based sources on which phytoplankton thrive and, consequently, higher values of zooplankton and fish larvae followed the trend. Highest phytoplankton density was found during the Northeast Monsoon (NEM) season and distributed mainly in the northern stations of Kiunga, Kiwayu, Lamu and Ungwana Bay (Fig 5.4.1). The high density was caused by a diatom bloom of *Chaetoceros sp*. Blooms can form in coastal or oceanic waters, most frequently when the water has been calm for some time and surface temperatures exceed 27°C. Dominant phytoplankton species found during both phases of the monsoon was the Cyanobacteria *Ocillatoria* sp and diatoms *Chaetoceros sp* and *Rhizosolenia sp*. Other common species were *Bacteriastrum* sp *Protoperidinium* sp, *Coscinodiscus* sp, *Alexandrium sp*, *Oscillatoria sp* and *Ostreopsis sp*.

Zooplankton abundance and diversity

The zooplankton density was higher at the northern coast of Kenya concomitant with the phytoplankton distribution off Lamu (Fig. 5.4.2). High occurrence of zooplankton in the north was associated with copepods *Neocalanus sp* and

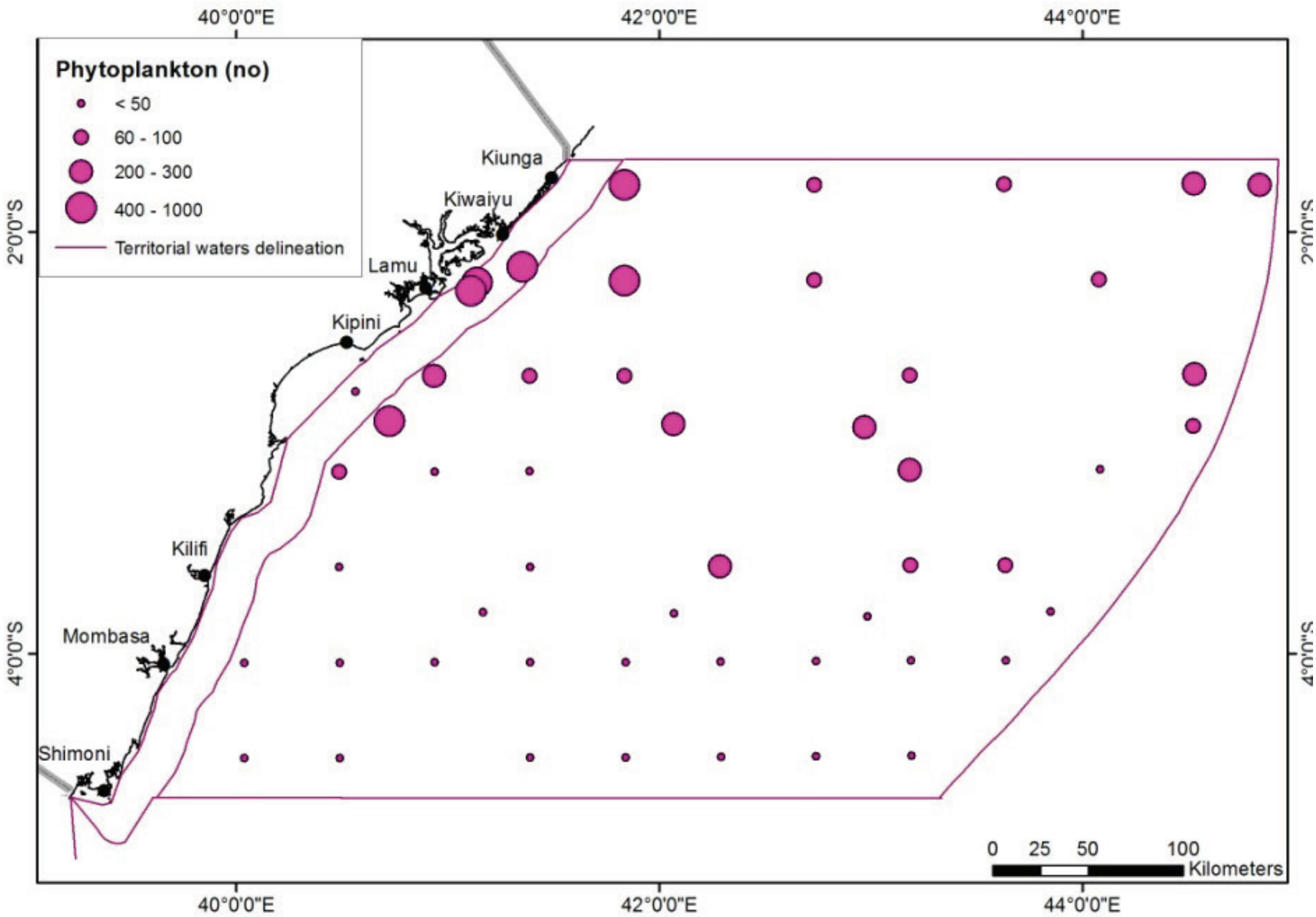

Figure 5.4.1: Distribution of phytoplankton (no m^{-3}) in Kenya's Territorial waters and EEZ

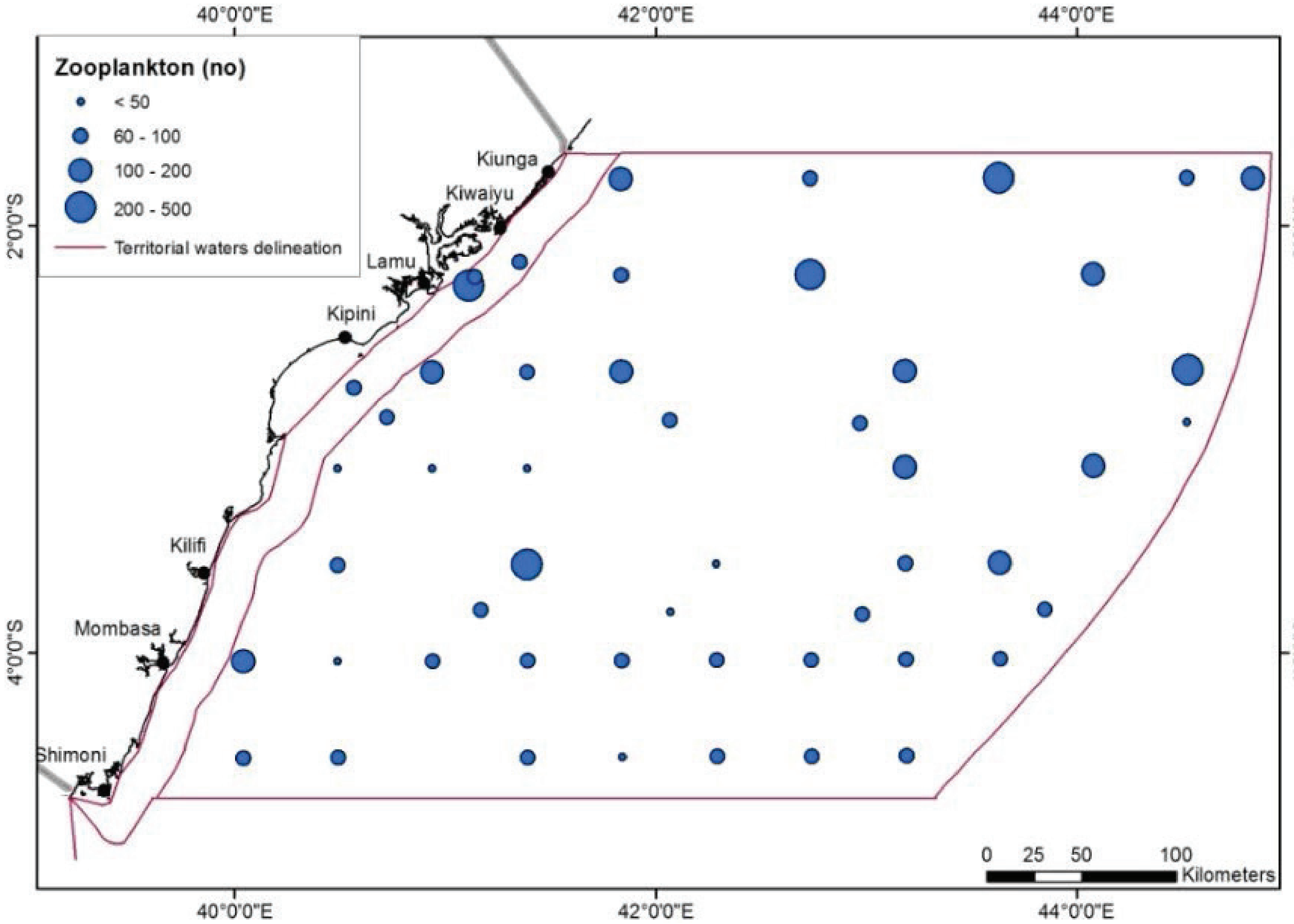

Figure 5.4.2: Distribution of zooplankton (no m⁻³) in Kenya's Territorial waters and EEZ

Calanoides carinatus. *Calanoides carinatus* is associated with upwelling areas in the northern coast of Kenya and Somali (Smith 1992; Hitchcock *et al*., 2002; JGOFS Report, 2003). High distribution was also observed off Kilifi and Mombasa during the NEM season (Fig. 5.4.2). Other common species encountered were *Oithona sp*, *Oncaea sp* and *Corycaeus* sp which were present in all sampling stations.

Composition and distribution of fish larvae

Generally higher densities of fish larvae were encountered in the northern coast of Kenya off Kiunga, Lamu and Ungwana Bay (Fig. 5.4.3). This high density encountered was attributed to high numbers of Snake mackerel *Gempylus serpens* larvae. In the south coast, high values were observed off Shimoni. Species of larvae of commercial value recorded included Southern Blue fin Tuna (*Thunnus maccoyi*) and Little Tuna (*Euthyunnus affinis*) (Plate 5.4.2).

Other species included Yellowfin Tuna (*T. albacares*), Skipjack Tuna (*Katsuwonus pelamis*), the billfish *Tetrapturus sp*, the halfbeak *Oxyporhamphus sp*, as well as Carangidae and Holocentridae species. The larvae were found distributed at different densities along the coast of Kenya which may indicating possible spawning sites. For instance, significantly higher densities of the Snake mackerel *Gempylus serpens* were found in the territorial waters off Kilifi and Mombasa; while skipjack tuna larvae were predominant off Kilifi and Mombasa.

In total, 44 families were identified during the cruises along the coast both from the Territorial waters and EEZ (Fig. 5.4.4) Territorial waters were considered as distance from the shore to 12nm while EEZ waters included area sampled from 12nm to 250nm. Zonation in distribution of larvae was observed for different families with respect to territorial an EEZ waters (Fig. 5.4.4). Dominant fish larvae families in territorial waters were Engraulidae (anchovies), Scombridae (Tunas) and Carangidae (Jacks) whereas in EEZ waters dominant families were Scombridae, Gempylidae (Snake mackerels), Exocoetidae (Flying fish) and Nomeidae (Driftfishes).

Engraulids were mainly represented by *Stolephorus*

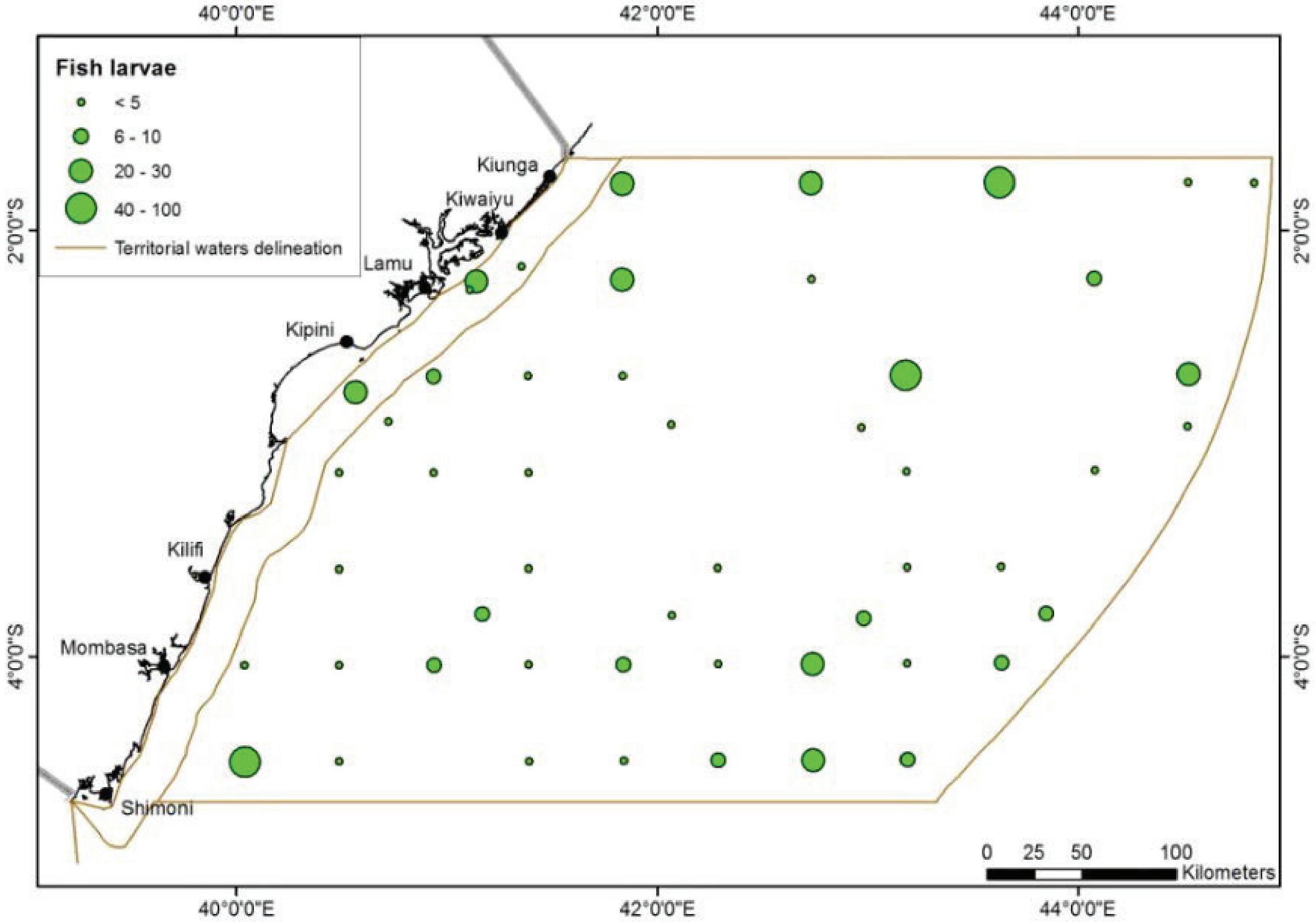

Figure 5.4.3: Fish larvae distribution (no m^{-3}) in Kenya's Territorial and EEZ waters.

sp (Plate 5.4.2), while scombrids were represented by *Thunnus albacares*, *Thunnus macoyii*, *Thunnus obesus*, *Katsuwonis pelamis*, *Euthynnus affinis* among others. Carangids were mainly represented by *Caranx sp*, *Elagatis bipinnulata*, *Scomberoides sp* (Plate 5.4.2), and *Seriolina sp* among other species. The presence of these larvae in Kenya's offshore waters is indicative of important breeding and nursery grounds for important commercial pelagic fishes.

5.4.3 Conclusion

Results from the RV Mtafiti cruise surveys represent the first documented account of plankton diversity and distribution in Kenya's offshore waters. The findings contribute new knowledge that is crucial for comparing with other oceanographic surveys in the western Indian Ocean (WIO) region such as the Fridtjof Nansen and IIOE cruises. The high productivity encountered in the northern Kenya is indicative of waters with high nutrient content and consequently high abundance of phytoplankton and zooplankton. However patches of productivity were witnessed offshore indicative of the patchy nature of planktonic communities. The distribution of plankton correlated to nutrient supply with high plankton production to the north indicative of upwelling.

The observed larval distribution patterns of commercially important tuna and tuna-like species is indicative of the potential spawning grounds especially during the NEM season. Earlier test cruise surveys from Shimoni to Lamu in the territorial and EEZ waters suggest that there may exist important breeding grounds for tunas off Lamu, Kilifi and Mombasa waters. Studies in the WIO (between Madagascar and the Equator) suggest that spawning of the tuna species *K. pelamis* (Skipjack) and *T. albacares* (Yellowfin) and *T. Obesus* (Big Eye) occurred in summer months (November-May) when temperature are high and preferentially in high salinity (Conrad and Richards, 1982). Similarly, studies of *T. alalunga* (Albacore) and *K. pelamis*, in the WIO using histological analyses and gonadosomatic index analysis have documented spawning to occur from November to January in the east coast of Madagascar (Grandea *et al*., 2014; Dhurmeea *et al*. 2016). Future research will focus on understanding seasonal patterns and the environmental factors that may be influencing observed patterns. Standardization of plankton sampling protocols within the WIO region is however recommended to make data comparisons easier.

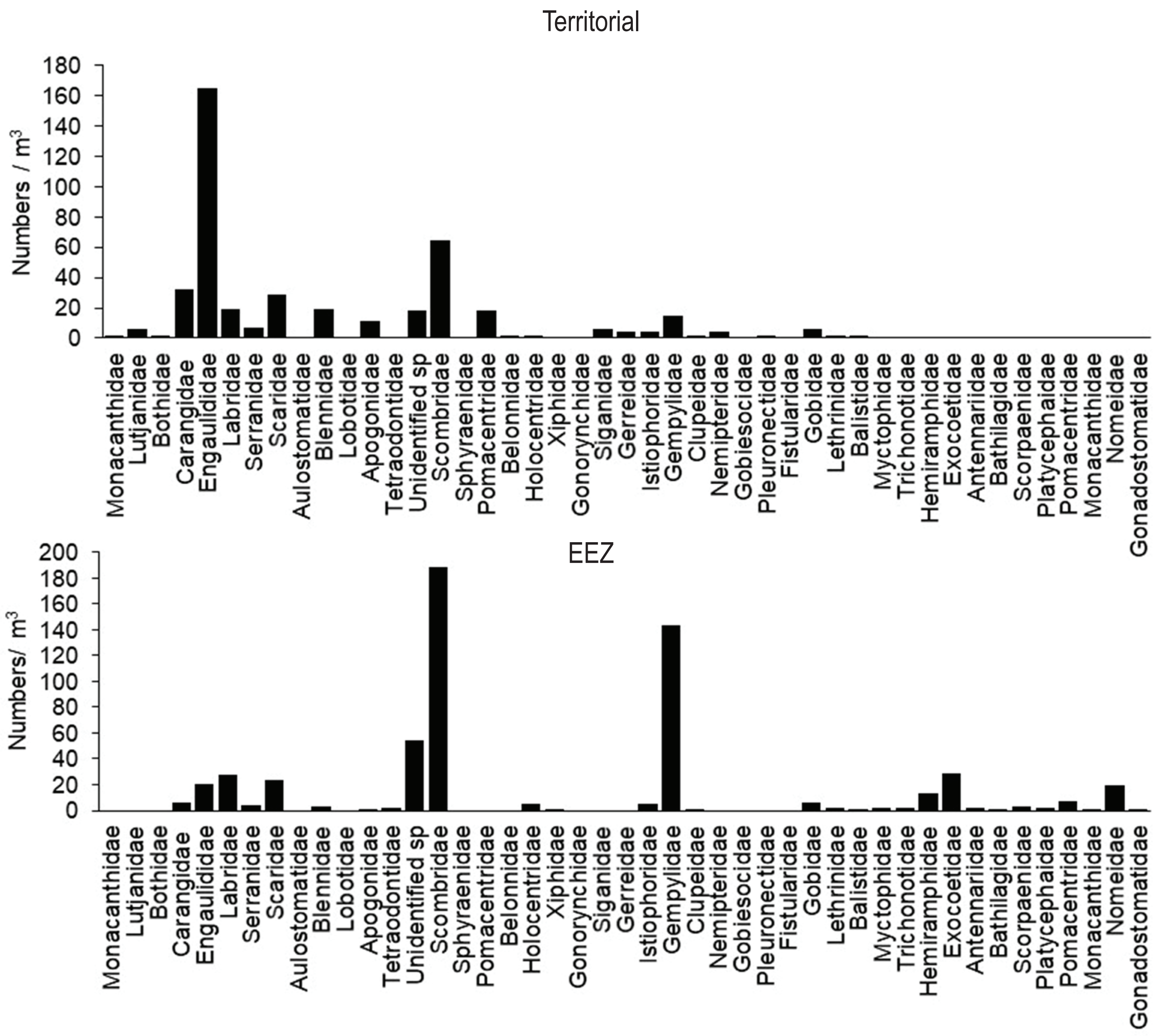

Figure 5.4.4: The relative abundance of fish larvae in Territorial and EEZ waters of Kenya

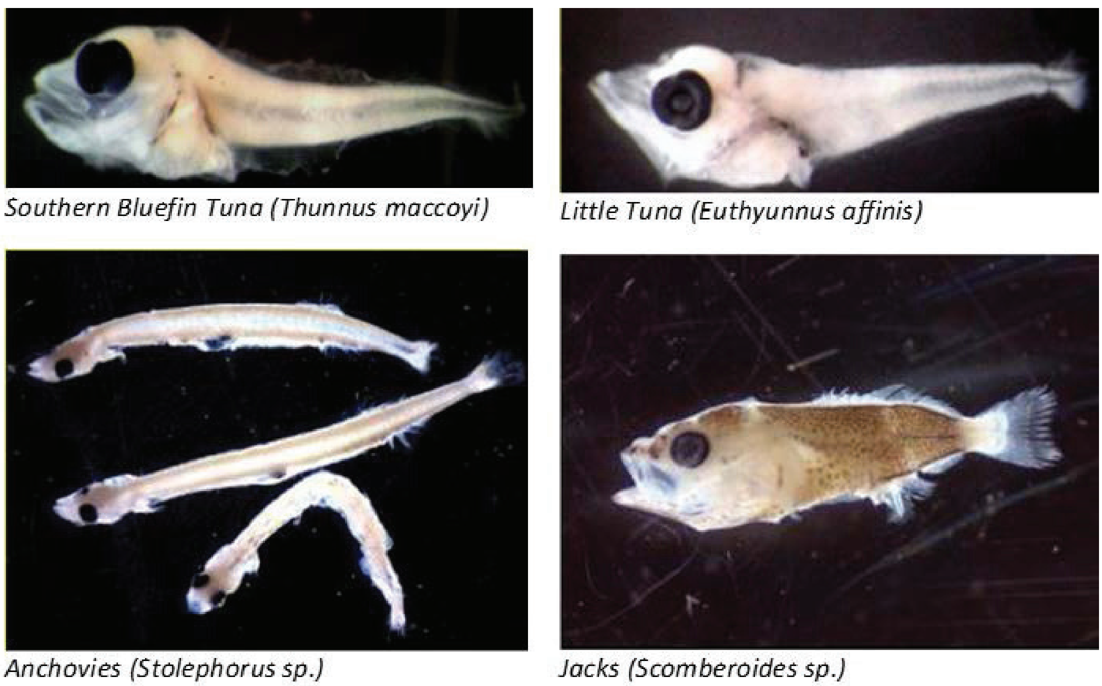

Plate 5.4.2: Photos of some fish larvae in samples collected from Kenya's offshore waters

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5.5 Fish Abundance and Exploitation Trends

Gladys Okemwa, Edward Kimani, Johnstone Omukoto, Nina Wambiji, Harrison Ong'anda, Chrispine Nyamweya, Noah Ngisiang'e, Amon Kimeli and Elizabeth Mueni

5.5.1 Introduction

Kenya's marine capture fisheries contribute immensely to the food and nutritional security of coastal communities, supports many livelihoods and generates income and foreign exchange earnings. The marine fishery sector presently contributes approximately 10% of the total annual national fishery production which is estimated to be about 164,310Mt, worth about KES 24 Billion in 2015 (Government of Kenya, 2015). The resources are exploited by small scale, semi-industrial, industrial, recreational fisheries, while EEZ resources are mainly exploited by Distant Water Fishing Nations (DWFN), mainly the EU and the Far East Asian nations. Within the concept of the Blue Economy initiative, the Kenya Government is embracing the potential for exploiting untapped offshore fisheries resources in the EEZ as well as improving other fisheries resources to support economic development. The Blue Economy prioritizes the oceans as "development spaces" integrating new resource explorations to enhance long term economic benefits.

Goal 14 of the Sustainable Development Goals (SDGs) aims "To conserve and sustainably use the oceans, seas and marine resources for sustainable development" further complements the Blue Economy initiative in addressing poverty and food security. SDG Indicator 14.4.1 prescribes the target of '*effectively ending overfishing and IUU fishing, and implementing science-based fishery management plans by 2020*. A science-based approach is essential to meeting the SDG targets as well as the development of the Blue Economy. There has also been a shift towards ecosystem-based fisheries management which heavily relies on understanding exploitation and fish distribution patterns as well as the habitat linkages.

RV Mtafiti provides a unique opportunity to improve fisheries data collection and information for on Kenya's marine fisheries and environment. This section provides a general overview on of marine fisheries production and details preliminary estimates of fish biomass and distribution in the offshore waters based on results of hydroacoustic surveys undertaken by onboard RV Mtafiti. The offshore pelagic fisheries catches are further characterized based on longline catch data collected through the KMFRI scientific Observer Programme.

5.5.2 Overview of marine catch production

Kenya's annual marine catch production has been reported to fluctuate around 9000Mt since the 1990s, with the bulk (about 80%) landed by small-scale artisanal fishers. Fishing is mostly concentrated in the nearshore areas within mangroves, seagrass beds and coral reefs environments. Commercially

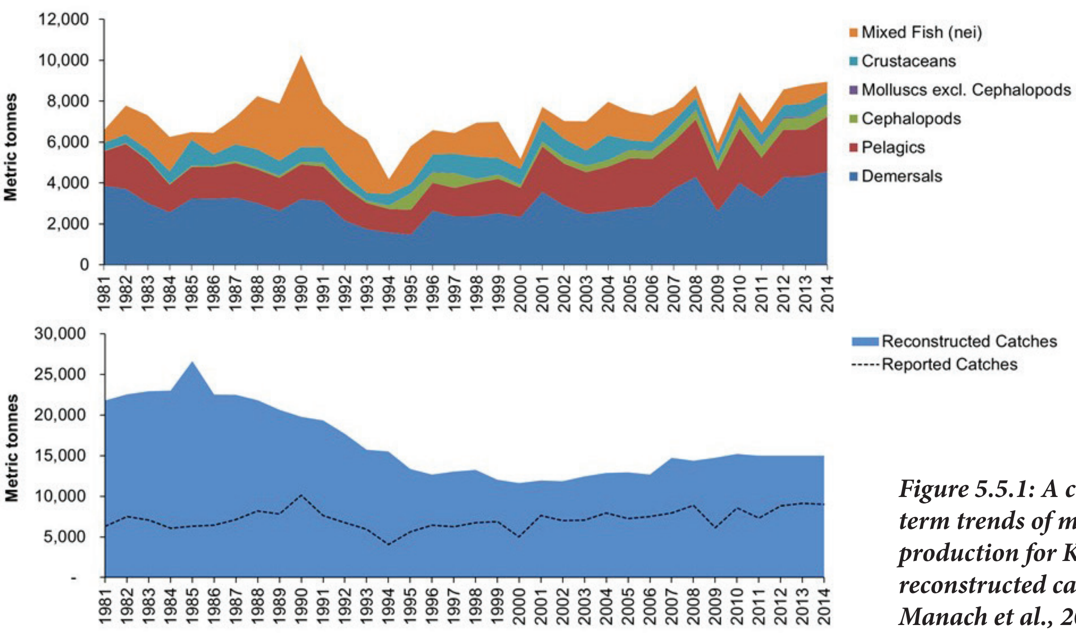

Figure 5.5.1: A comparison of long-term trends of marine fisheries production for Kenya based on reconstructed catches (Source: Le Manach et al., 2015).

important species targeted include demersal reef fishes, coastal tunas, mackerels, barracuda, crabs, prawns, lobsters, octopus and squids. Landings of demersal finfish species represent around 50% of the total fish catches.

Research and anecdotal evidence suggest over-exploitation in some areas as well as some fisheries. However, the annual production trends have been relatively stable since the 1990s likely influenced by increasing fishing effort in terms of the number of fishers, target species, time spent fishing as well as changes in gear use as fishers switch to more efficient gears such as ringnets (Ochiewo, 2004; Okemwa *et al*., 2017). Catches also vary seasonally, influenced by the northeast monsoon (NEM), from October to April, the southeast monsoon (SEM) from May to September.

The 2016 frame survey documented 197 landing sites along the Kenya coast. Collection of accurate fisheries data is challenging as most of the sites are highly porous and located in remote areas which are difficult to monitor effectively. Consequently, a high proportion of the marine fishery catches go unreported leading to underestimation. However, there have been recent efforts to improve the estimation of annual marine catches through reconstruction (Le Manach *et al*., 2015) as well as sample based monitoring (Government of Kenya, 2016) which project the annual catches to range between 23,000 and 27,000Mt respectively (Fig. 5.5.1).

5.5.3 Fish abundance and catch distribution in nearshore waters

KMFRI implements a land based Catch Assessment Survey (CAS) Programme to collect long term data on fishing effort, catch rates (Kgfisher^{-1}day^{-1}), catch composition (species and sizes) in selected landing sites within Kwale, Mombasa, Kilifi, Tana River and Lamu counties. During 2016, the three most commonly used gear types along the Kenya coast include basket traps, gillnets of various mesh sizes and handlines.

The catch rates for the different gear types vary among the landing sites ranging from 2.8 and 4.4Kgfisher^{-1}Day^{-1} for basket traps with the lowest being at Gazi (Kwale County) and the highest at Old Port (Mombasa County) (Fig. 5.5.2.). The catch rates for gillnets ranged from 2.5Kgfisher^{-1}Day^{-1} in Msambweni to 5.3Kgfisher^{-1}Day^{-1} in Kipini, while handlines ranged from 1.1Kgfisher^{-1}Day^{-1} in Ozi to 45.4Kgfisher^{-1}Day^{-1} in Kipini. The notably high catch rates for handlines in Kipini are attributed to the rich fishing grounds of the North Kenya Banks.

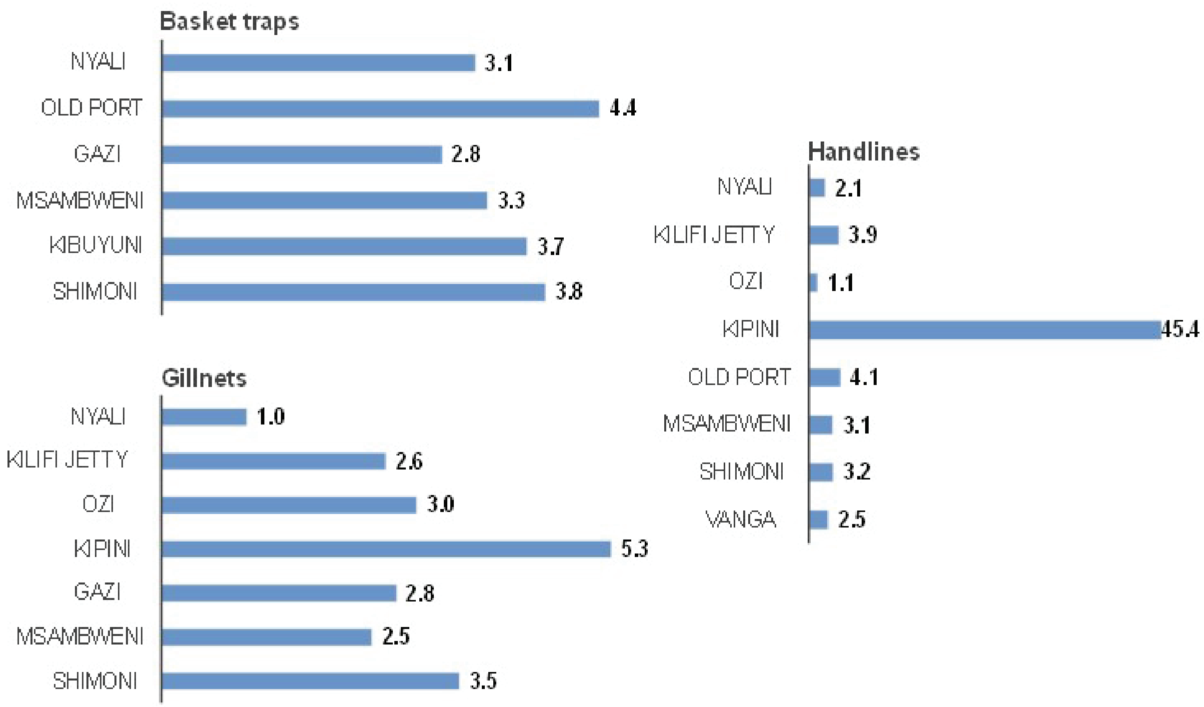

Figure 5.5.2: Variation in the average Catch per Unit Effort (Kgfisher^{-1}Day^{-1}) for the three most common gear types used at the landing sites that were monitoring during 2016 CAS

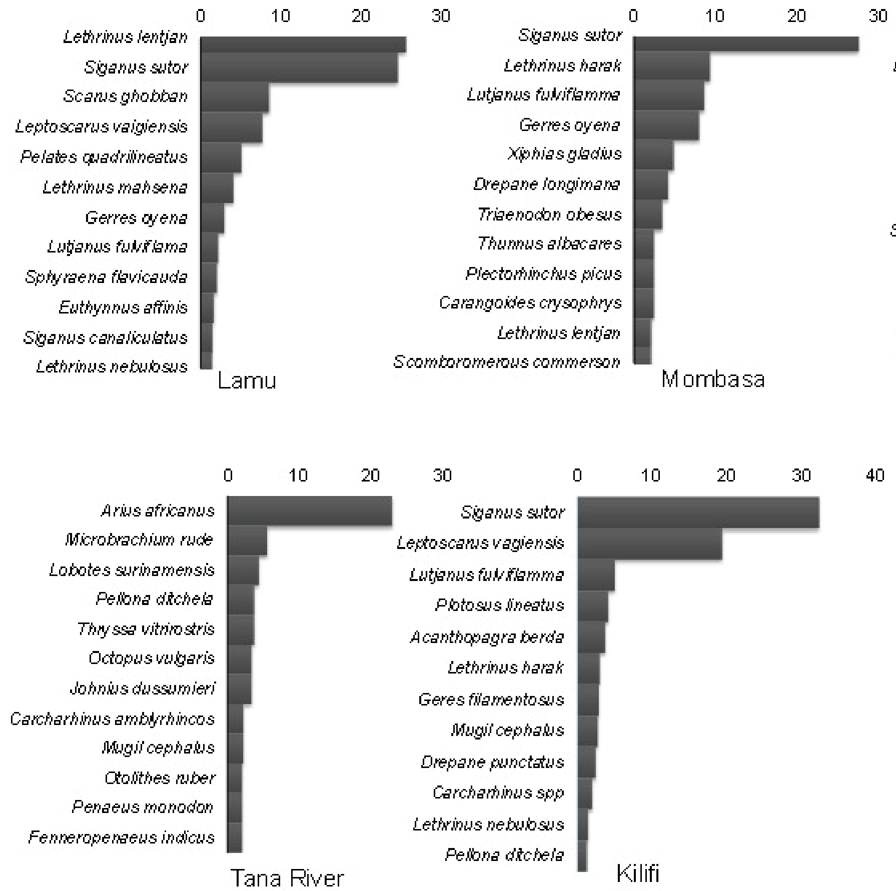

Figure 5.5.3: Relative abundance (%) of the most abundant species by number in the sampled catches from the coastal counties that were monitored during 2016/2017 period

The finfish families abundantly landed included Siganidae, Lethrinidae and Scaridae, which all together constituted over 50% of the catches. The most common species in the catches included the rabbitfish *Siganus sutor* making up 20 to 32% of the total catches, the emperors *Lethrinus lentjan* and *Lethrinus harak* and the parrotfish *Leptoscarus vaigiensis* (Fig. 5.5.3). The most common species captured among the medium pelagic species were the barracuda *Sphyraena flavicauda*, and the tuna *Euthynnus affinis*.

Dominant fin fish species landed at Tana River County were those that utilize estuarine conditions such as the marine catfish *Arias africanus*, and the triple tail *Lobotes surinamensis*. The nearshore areas continue to face heavy fishing pressure due to overfishing and use of destructive fishing gears such as beach seines. Evidence of overfishing is well documented and includes declining catch rates and changes in the species composition of catches, leading to habitat degradation and increasing incidence of resource use conflicts due to loss of livelihoods (Samoilys *et al*., 2017).

5.5.4 Fish distribution in Kenya's territorial and EEZ waters

Globally, tuna and tuna-like resources are valued at more than 42 Billion USD, with the Indian Ocean contributing about 20 – 25% of the production. In 2003, the IOTC plot of geographical distribution of main tuna species in the South-West Indian Ocean (SWIO) showed that Kenya lies at the upwelling region of the ocean and supports the second most productive tuna fishing grounds after Somalia. Kenya annually licenses about 30 purse seiners, mainly from the EU, and up to 9 long liners, mainly Taiwan, China and Japan, who pay a license fee to access stocks within Kenya's EEZ. The license obliges the submission of catch data in prescribed log-books.

Although the data is often under reported and provides little biological information, some useful information on the distribution patterns of the fisheries resources can be obtained. The use of independent scientific observers on-board the vessels also provides an opportunity to collect biological information on the species and size structure of the catches as well as discards, and to validate the composition and volume of fish that is reported by the Distant Water Fishing Nations (DWFN).

Kenya's EEZ lies within the richest tuna belt of the SWIO. FAO in (1981) estimated that a maximum sustainable yield from Kenya's marine fishery could be 150,000Mt, with small pelagic species estimated to range between 18,000 to 20,000Mt (Ruwa *et al*., 2003). The pelagic fisheries resources within Kenya's EEZ are mainly exploited by DWFN through annual licenses. There is a growing recognition of the opportunities to gain by developing the fishery within the EEZ. However, the abundance and fish distribution patterns in Kenya's offshore waters resources remains poorly documented. In the past few years, KMFRI has undertaken hydroacoustic surveys on RV Mtafiti and deployed fisheries observers in commercial long line vessels to collect information on the abundance of fish in the Kenya EEZ.

5.5.5 Fisheries hydroacoustic surveys

The survey of Kenya's offshore waters was grouped into four blocks: Territorial waters; EEZ off Lamu County (Block 1); EEZ off Kilifi County (Block 2); and EEZ off Kwale County (Block 3) (detailed in Section 5.1). Using the target strength of tuna to calculate

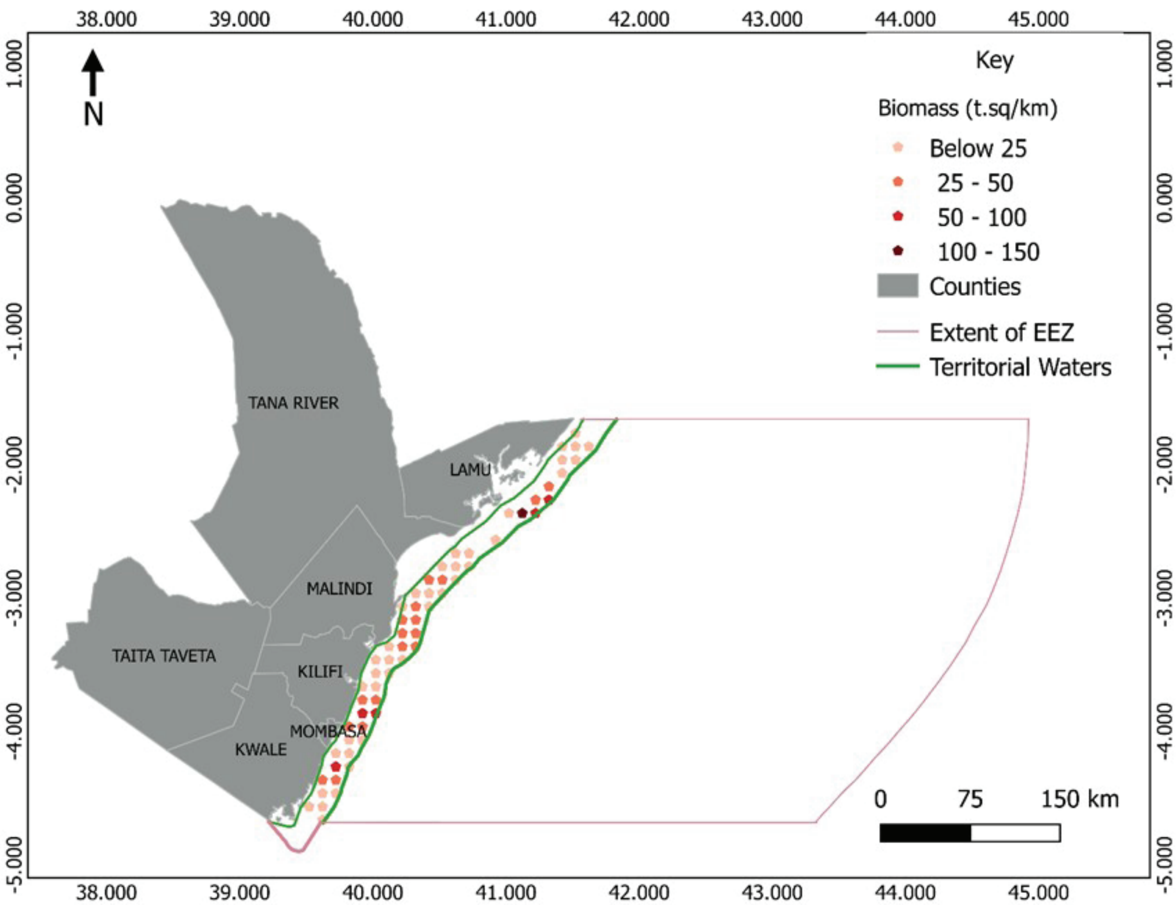

Figure 5.5.4: Spatial distribution of fish biomass (MtKm^{-2}) in the Kenyan Territorial waters

Table 5.5.1: Estimated fish densities and the total area covered by the RV Mtafiti surveys in the Kenya Territorial waters during December, 2016

EEZ	Survey Dates	0-100m	100-350m	350-1000m	Total Area (Km²)
Block 1	25th Nov-18th Dec 2016	5.53	0.6	0.003	52,383
Block 2	6th-21st Feb 2017	10.55	5.24	0.0006	47,258
Block 3	5th-22nd May 2017	16.38	1	0.124	52,522

Table 5.5.2: Estimates of fish densities (MtKm^{-2}) in Kenya's EEZ using hydroacoustic onboard RV Mtafiti

EEZ	Survey Dates	0-100m	100-350m	350-1000m	Total Area (Km^2)
Block 1	25th Nov-18th Dec 2016	5.53	0.6	0.003	52,383
Block 2	6th-21st Feb 2017	10.55	5.24	0.0006	47,258
Block 3	5th-22nd May 2017	16.38	1	0.124	52,522

indicative biomass, the highest fish abundance was observed in the territorial waters was off Lamu and the North Kenya banks in Malindi (Fig. 5.5.4, Table 5.5.1). In the EEZ, most (90%) of the fish biomass was concentrated within the upper 100m layer of the water column, while about 9% of the fish biomass was in the mesopelagic layer (100-350m), and only 1% was detected beyond the 350m depth (Table 5.5.2).

5.5.6. Industrial longline fishing effort and catches

It was not possible to determine the assemblage structure (species and size structure) of the detected fish biomass. However, an assess-

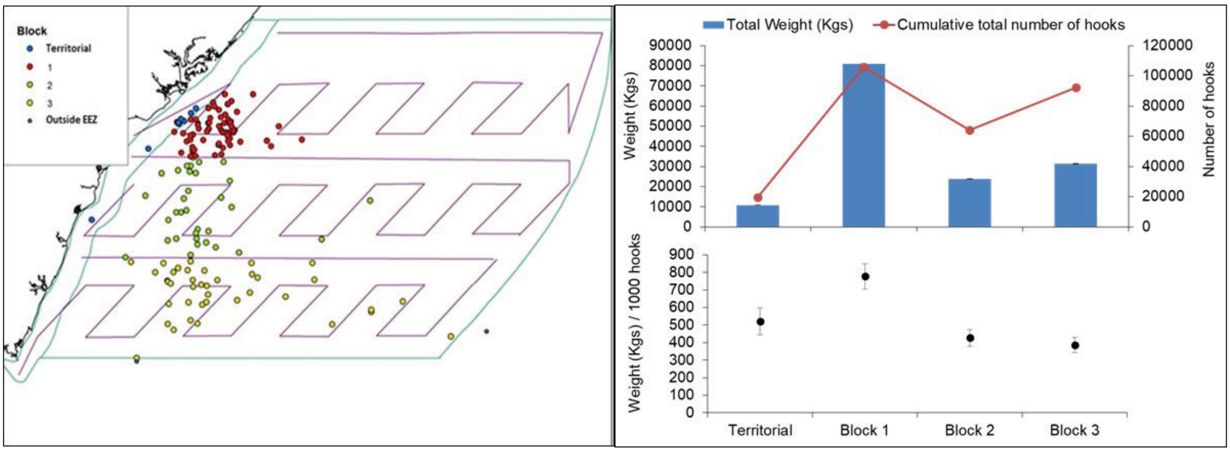

Figure 5.5.5: Spatial distribution of commercial longline fishing effort, and the total catch and catch per unit effort (Kg 1000 hooks^{-1}) of commercial longliner fishing in Kenya's EEZ during April – December 2016

ment of the catches of commercial vessels fishing within the EEZ provide an indication of the composition of the harvestable biomass. The distribution of industrial long line catches and fishing effort clustered into the RV Mtafiti survey blocks is shown in Fig. 5.5.5. The fish catches were highest in Block 1 (55% of the total catches), followed by Block 3 (22%). The highest fishing effort (total number of sets) was also in Block 1 (43%), followed by the Block 3 (26%).

The total catch set^{-1} was 972 ± 58Kg, while the average catch per unit effort was 564 ± 37Kg 1000 hooks^{-1}. The highest average catch per unit effort of 777 ± 71Kg 1000 hooks^{-1} was in Block 1 (Off Lamu) and the lowest (386 ± 43Kg) in the Block 3. Cumulatively, the highest catches were during April to June, with the highest catch rates occurring in April. On the other hand, the lowest catches were recorded in September (Fig. 5.5.6). Despite high fishing effort during October and November, the catches remained lower than during the NEM months. Tuna species constituted about 52% of the longline catches dominated by Yellowfin tuna (35%) of the total catches, followed by Bigeye tuna constituting 13%. Yellowfin tuna catches were mainly caught from Block 1 (Off Lamu), while the Bigeye tuna were mainly fished from Block 3 (49%) and Block 1 (34%) (Fig. 5.5.7).

Sharks were mostly captured in Block 1 (56%) while Swordfish was mainly caught in Block 2 (32%) and 3 (34%). The variation in abundance of tuna species may be influenced by the seasonal dynamics as well as the fishing strategies used in terms of the fishing depths and hook sizes. Results from the scientific fisheries observer programme showed a slight variation in the composition of the catches with the dominant species being Bigeye tuna (26%), Swordfish (24%) and Yellowfin tuna (19%).

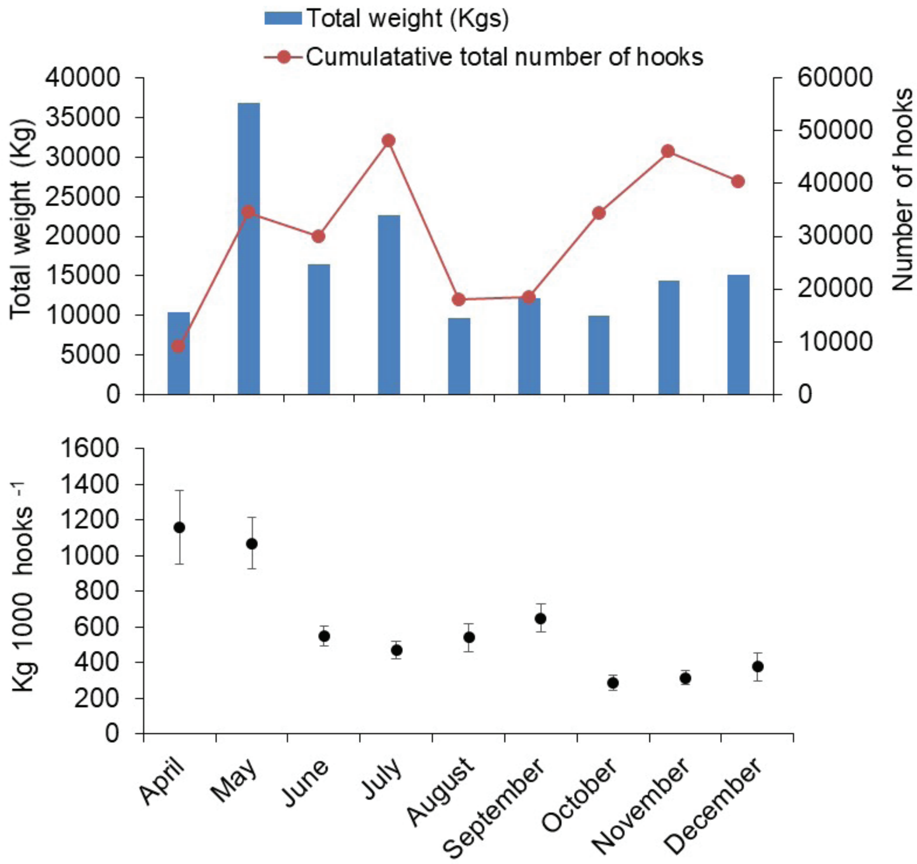

Figure 5.5.6: The temporal trends of commercial longline catches in the EEZ. (a) longline pelagic catches and fishing effort and (b) the standardized catch rates (Kg 1000 hooks^{-1}) in Kenya's EEZ during April – November 2016

of the stocks. The hydroacoustic data generated from RV Mtafiti forms the first description of fish distribution and abundance in the entirety of Kenya's territorial and EEZ waters. There is need to further improve the accuracy of fish biomass estimates using hydroacoustics by validating the composition of detected fish aggregations. The preliminary density estimates reported herein are indicative of the likely fish abundance and distribution patterns. Future prospects in hydroacoustic fish stock assessment include conducting ex-situ target strength experiments and validation of the composition of fish aggregations using mid-water trawling.

The important contribution of fisheries knowledge and data from the catch assessment, the RV Mtafiti surveys and the KMFRI Scientific Observer Programme is demonstrated in the findings. Deployment of scientific fisheries observers onboard commercial fishing vessels over the long-term will continue to provide essential data and information to better understand the status and dynamics of the harvested stocks. The

The secondary target species included Striped marlin and Blue shark (Table 5.5.3). New information on discards was also obtained. The discarded species were dominated by the shark *Carcharhinus longimanus* which constituted approximately 73% of the discards, followed by the Snake mackerel *Gempylus serpens* (17%), puffer fishes (3%) and other mixed species (*Galeocerdo cuvier*, Molas, *Alepisaurus ferox*, rays) which constituted less than 2%. The observer data also revealed high bycatch of some endangered shark species such as the *Scalloped hammerhead*, *Sphyrna lewini*.

5.5.7 Conclusion

Data collection on the small scale fishery has continued to improve over the years and will continue to support science-based decision-making in the management

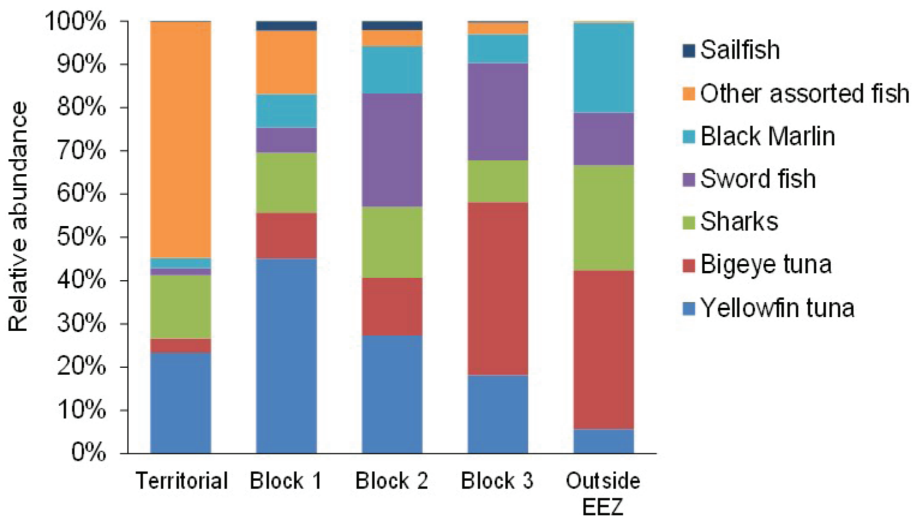

Figure 5.5.7: Species composition of reported commercial longline catches clustered by relative abundance within the RV Mtafiti survey blocks in the Territorial waters and EEZ

Table 5.5.3: Species composition of longline catches from a total sampled weight of 22,486Kg collected by KMFRI scientific observers between October and November 2016

No.	Scientific name	Common name	Wet weight,Kg	Percentage
1	*Thunnus obesus*	Bigeye tuna	5949	26.46
2	*Xiphias gladius*	Swordfish	5496.5	24.44
3	*Thunnus albacares*	Yellowfin tuna	4193.4	18.65
4	*Prionace glauca*	Blue shark	2964	13.18
5	*Tetrapturus audax*	Striped marlin	1952	8.68
6	*Makaira nigricans*	Blue marlin	308	1.37
7	*Sphyraena barracuda*	Great barracuda	267.2	1.19
8	*Carcharhinus limbatus*	Blacktip shark	267	1.19
9	*Lepidocybium flavobrunneum*	Escolar	240	1.07
10	*Carcharhinus longimanus*	Oceanic whitetip shark	212	0.94
11	*Coryphaena hippurus*	Common dolphinfish	146	0.65
12	*Isurus oxyrinchus*	Shortfin mako	130	0.58
13	*Makaira nigricans*	Blue marlin	120	0.53
14	*Taractichthys longipinnis*	Bigscale pomfret	102	0.45
15	*Galeocerdo cuvier*	Tiger shark	50	0.22
16	*Alepisaurus ferox*	Longnose Lancetfish	34.4	0.15
17	*Sphyrna lewini*	Scalloped hammerhead	21	0.09
18	*Acanthocybium solandri*	Wahoo	15	0.07
19	*Gempylus serpens*	Snake mackerel	9.4	0.04
20	*Tetraodontidae sp.*	Puffer fish	6	0.03
21	*Katsuwonus pelamis*	Skipjack tuna	3	0.01

combined outputs from the hydroacoustic surveys, industrial logbook returns and scientific observer data on Kenya's EEZ fisheries resources provides an important milestone in Kenya's marine fisheries research to inform development within the Blue Economy initiative.

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5.6 RV Mtafiti Fishery Observer Programme

Johnstone Omukoto, Pascal Thoya and Edward Kimani

5.6.1 Introduction

The requirement to have fishery observers onboard all fishing vessels is enshrined in Kenya's Fisheries Management and Development Act, 2016, Article 147. The Fisheries Observer Programme is responsible for providing the training and support necessary for deploying observers on board fishing vessels in order to collect fisheries-dependent information essential to achieving the fisheries management objectives. An Observer Programme is structured as an organizational unit composed of different actors in charge of fisheries observation planning, deployment logistics, data handling and reporting as depicted in Fig. 5.6.1.

There are two categories of observers: Compliance Fisheries Observers and Scientific Fisheries Observers. The Marine Fisheries Observer Programme that is executed by KMFRI is scientific in nature. The scientific observers board fishing vessels to collect unbiased data and report on technical, regulatory, scientific and economic aspects of a fishing operation. They work during normal fishing operations to verify and accurately record information on the fishing location, gear configurations, and catch composition among other parameters. They are usually the only independent data collection source for this information. The observers are not employed in an enforcement role and their duty is to collect accurate fisheries and biological data only.

The genesis of the Marine Fisheries Observer Programme in Kenya can be traced back to the South West Indian Ocean Fisheries Project (SWIOFP) (Groenveld and Heinecken, 2010). Five Kenyan observers were trained under SWIOFP in 2010 and the rollout of the Observer Programme tentatively began during 2012-2013 under the Kenya Coastal Development Project (KCDP). In 2016, a Prawn Fisheries Observer Strategy for the period 2016-2020 was developed to monitor the implementation of the Prawn Fishery Management Plan. This was later expanded to include a trial deep water trawl fishery aimed at determining the potential of deep water crustacean trawl fishery in Kenya. KMFRI has also deployed observers on one of the industrial long-line vessels registered in Kenya.

The efforts towards establishing the Marine Fisheries Observer Programme in Kenya emerged from the continued realization that the marine fishery sector is significant to the overall economy of Kenya as well as the coastal region by contributing to employment, food security and income generation through local and export markets. The Programme has also been identified as a key component of fisheries management within the Blue Economy development initiatives that are ongoing (Kenya Sector Plan for the Blue Economy, 2018-2022).

Current information on the status and exploitation of different marine fisheries resources is required to update management regulations and management plans and provide guidelines for the development of new management regulations. Towards this, KMFRI jointly collaborates with the Kenya Fisheries Service (KeFS) to run the Marine Fisheries Observer Programme, which entails the planning and deployment of observers, as well as analysis of data gathered.

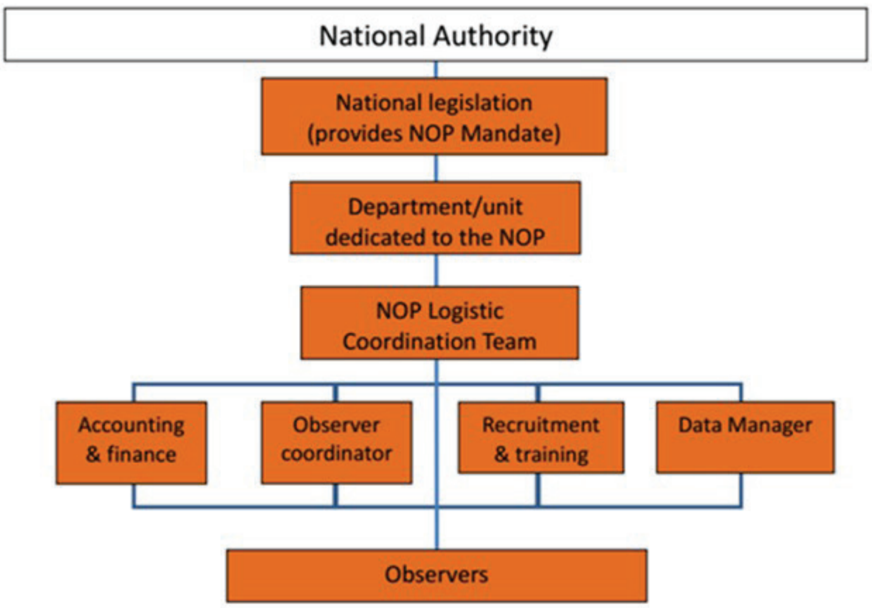


Figure 5.6.1: A generic organogram of a Fisheries Observer Programme (Source: AU-IBAR, 2016)

5.6.2 The marine fisheries observer programme strategy

The implementation strategy of the Marine Fisheries Observers Programme provides for the training, planning and deployment of fisheries observers onboard licensed semi-industrial and industrial fishing vessels in the Kenyan waters. To support monitoring of the semi-industrial prawn fishery within the Malindi-Ungwana Bay, KMFRI deploys one scientific observer onboard trawl vessels for 15 days with a possible extension of 5 days. On the other hand, observer deployments onboard industrial long-line fishing vessels take up to 60 days (with an average of 40-50 days). All observers collect catch data following protocols established by SWIOFP (Athayde, 2012; Groenveld and Heinecken, 2010). The data and information is collated, analysed and disseminated as technical reports, scientific publications, fact sheets and policy briefs to inform stakeholders on the status of the fishery and provide recommendations for management.

5.6.3 The shallow water semi-industrial prawn trawl fishery observation

The shallow water prawn trawl fishery employs semi-industrial outrigger steel trawlers ranging in size from 22-40m long and equipped with 300HP engines. The trawl fishing gears employed in the fishery is the funnel-shaped otter trawl fishing gear towed behind the vessels or on the sides for vessels using 2 trawl nets. The catch is cleaned, packaged, frozen and stored on board until the vessel capacity is filled up. The catch is then transferred to Mombasa for sale. A typical shallow water prawn trawl catch is shown in Plate 5.6.1.

Total catches and catch rates

Between 2011 and 2017, up to three prawn trawlers have been licensed to fish within the bay during the annual fishing season which starts from 1st April to 31st October each year guided by the Prawn Fishery Management Plan and the fisheries regulations gazetted in 2010. The distribution of fishery effort and the 3NM designated trawling zone is shown in Fig. 5.6.2 while annual catched a fishing effort are shown in Fig 5.6.3. Much of the fishing effort is concentrated at the mouth of the River Sabaki and River Tana and closer to the 3NM offshore borderline. The total catches ranged between 63Kg and 806Kg while the total for the target prawn ranged between 12Kg and 156Kg trawl^{-1} in 2016. During 2017, the total catches ranged between 118Kg and 661Kg trawl^{-1} while the catch for prawns was between 16Kg and 106Kg trawl^{-1}.

Target species

Plate 5.6.1: A typical shallow water prawn trawl catch, and inset is a shallow water prawn trawl vessel

Nine species of prawns were recorded during the 2016 shallow water prawn trawling. These included Indian white prawn (*Penaeus indicus*), Giant tiger prawn (*Penaeus monodon*), Speckled shrimp (*Metapenaeus monoceros*), Kuruma prawn (*Marsupenaeus japonicas*), Green tiger prawn (*Penaeus semisulcatus*), Peregrine shrimp

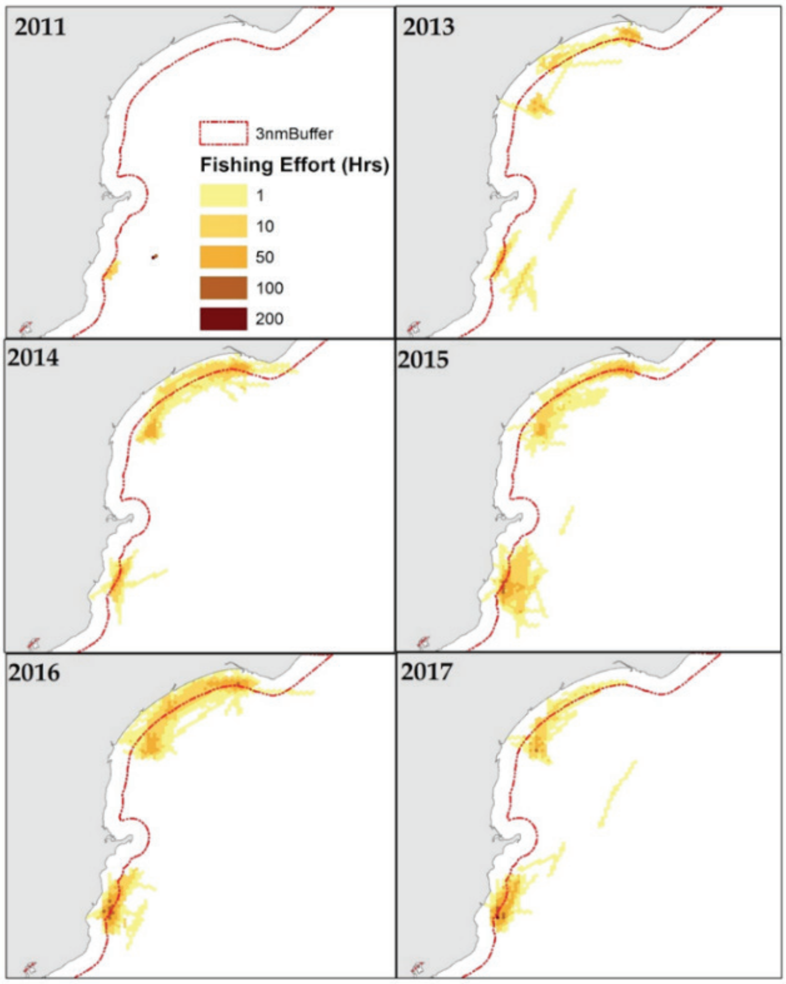


Figure 5.6.2: The spatial distribution of shallow water semi-industrial prawn fishing effort (number of hours) within the Malindi-Ungwana Bay between 2011 and 2017

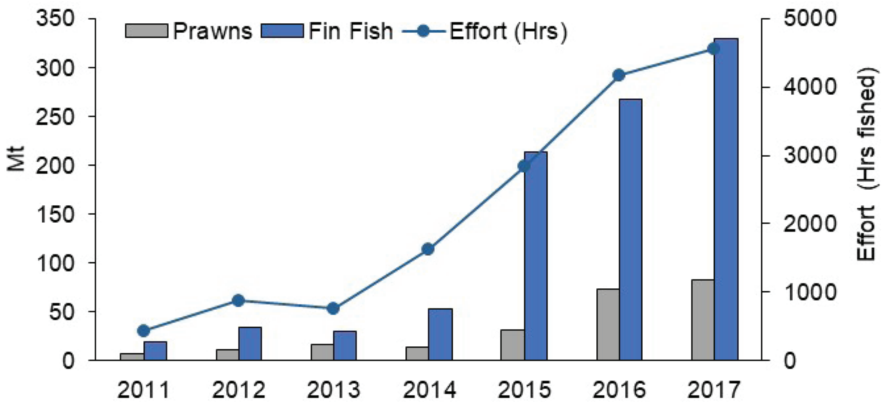


Figure 5.6.3: The trend in prawns and fish catches landed and the fishing effort between 2011 and 2017

(*Metapenaeus stebbingi*), the Southern rough shrimp (*Trachysalambria curvirostris*), the Western king prawn (*Melicertus latisulcatus*) and theGolden shrimp (*Plesionika martia*). The top four species (Plate 5.6.2) made up to 97% of the prawn catches. These are the Indian white prawn, which constituted 46%, Speckled shrimp (25%), Giant tiger prawn (20%) and Green tiger prawn with 6%.

Eight target species of prawns were recorded during the 2017 shallow water trawling season. The top species included the Indian white prawn which constituted 55%, the Speckled shrimp (13%), the Green tiger prawn (13%) and the Giant Tiger prawn (8%), making up 92% of the retained prawn catches (Table 5.6.1). Other prawn species recorded included Kuruma prawn, Golden shrimp, Peregrine shrimp, the Western king prawn and the Southern rough shrimp. Discarded prawn species was mainly Spider prawn (*Nematopalaemon tenuipes*) due to

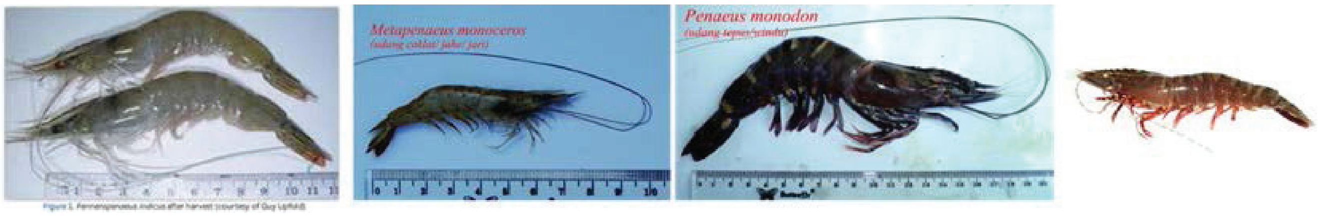


Plate 5.6.3: Four commonly caught prawn species in the trawl fishery in Kenya (From Left to Right: Penaeus indicus, Metapenaeus monoceros, Penaeus monodon and P. semisulcatus)

Table 5.6.1: Percent contribution of prawn species to the catches in 2016 and 2017

Common name	Species	2016	2017
Indian white prawn	*Penaeus indicus*	54.8	46.3
Speckled shrimp	*Metapenaeus monoceros*	12.7	25.2
Green tiger prawn	*Penaeus semisulcatus*	12.6	5.7
Giant tiger prawn	*Penaeus monodon*	8.4	19.7
Kuruma prawn	*Marsupenaeus japonicus*	2.4	1.1
-	*Palaemonidae shrimp*	1.5	0
Spider prawn	*Nematopalaemon tenuipes*	1.4	0
Witch prawn	*Penaeus canaliculatus*	1.1	0
Southern rough shrimp	*Trachysalambria curvirostris*	0.5	0
-	*Prawn larvae*	0.2	0
Peregrin shrimp	*Metapenaeus stebbingi*	0.1	0.1
Golden shrimp	*Plesionika martia*	0.0	0.1
-	*Mixed prawns*	4.4	1.7

its small unmarketable size.

Bycatch species

During 2016 (June to October) observations, approximately 85.8Mt of catch were examined of which 69.4Mt (81%) was retained and 19% was discarded. Prawns constituted approximately 27.3Mt (39%) of the retain catches. The retained bycatch species constituted finfishes (41.5Mt, 60%) and other species constituted 0.8Mt (1%) including sharks, crabs, cuttlefish, lobster and squids. During the 2017 (May – October) observations on ten fishing trips implemented, approximately 156.5Mt of catch were examined of which 103.4Mt (66 %) was retained and 53.1Mt (34%) was discarded.

The amount of discards in 2017 was 34% compared to 19% in 2016. The composition of the semi-industrial prawn trawl catches in 2017 was dominated by finfish followed by prawns and sea weeds, with other categories making less than one percent of the catch (Table 5.6.2). The mix of target, retained and bycatch species in a typical hauled catch is shown in Plate 5.6.4.

Table 5.6.2: The composition of shallow trawl catches at the Kenya coast during 2017

Category	Weight	Percent
Finfish	132198.5	84.5
Prawns	17480.3	11.2
Seaweeds and grasses	1957.7	1.3
Cnidaria	1779.4	1.1
Crabs	996.5	0.6
Trash	696.5	0.4
Lobsters	470.5	0.3
Other crustaceans	461.7	0.3
Jellyfish	107.8	0.1
Molluscs	85.9	0.1
Sea urchins	4.5	0.003
Echinoderm	60.1	0.0
Sharks	201.7	0.1
Sponges	2.9	0.002
Squids	12.1	0.008
Total	156516.1	

Over 150 species were retained with the top 35 contributing 89% of the catch while in 2017, over 170 species of finfish and other

Plate 5.6.3: An example of a hauled catch showing a mix of target, retained and bycatch species that are typically caught by shallow water prawn trawlers. A big ray caught as bycatch is shown in Plate A; while plate B has a turtle that was caught and released alive (Photo credit: Ben Ogola and Jibril Olunga)

organisms representing over 60 families were discarded (Fig. 5.6.4). Photos of some of the top retained bycatch finfish species caught are shown in Plate 5.6.5. The Tigertooth croaker, *Otolithes ruber* was dominant in the retained species making 20% of all the retained species.

Up to 107 species of finfish and other organisms representing 48 families were recorded in the discarded samples. The top 35 species constituted approximately 95% of the weight of discards (Fig. 5.6.4). The Indian pellona (*Pellona ditchela*) was the dominant species in the discards making 15% of the total discards, followed by Pugnose ponyfish *Secutor insidiator,* the Largehead hairtail (*Trichiurus lepturus*) and White barbel (*Galeichthys feliceps*).

5.6.4 Trial deep-water crustacean trawl fishing

Two vessels undertook deep water trawling trials targeting crustaceans with the aim of determining if

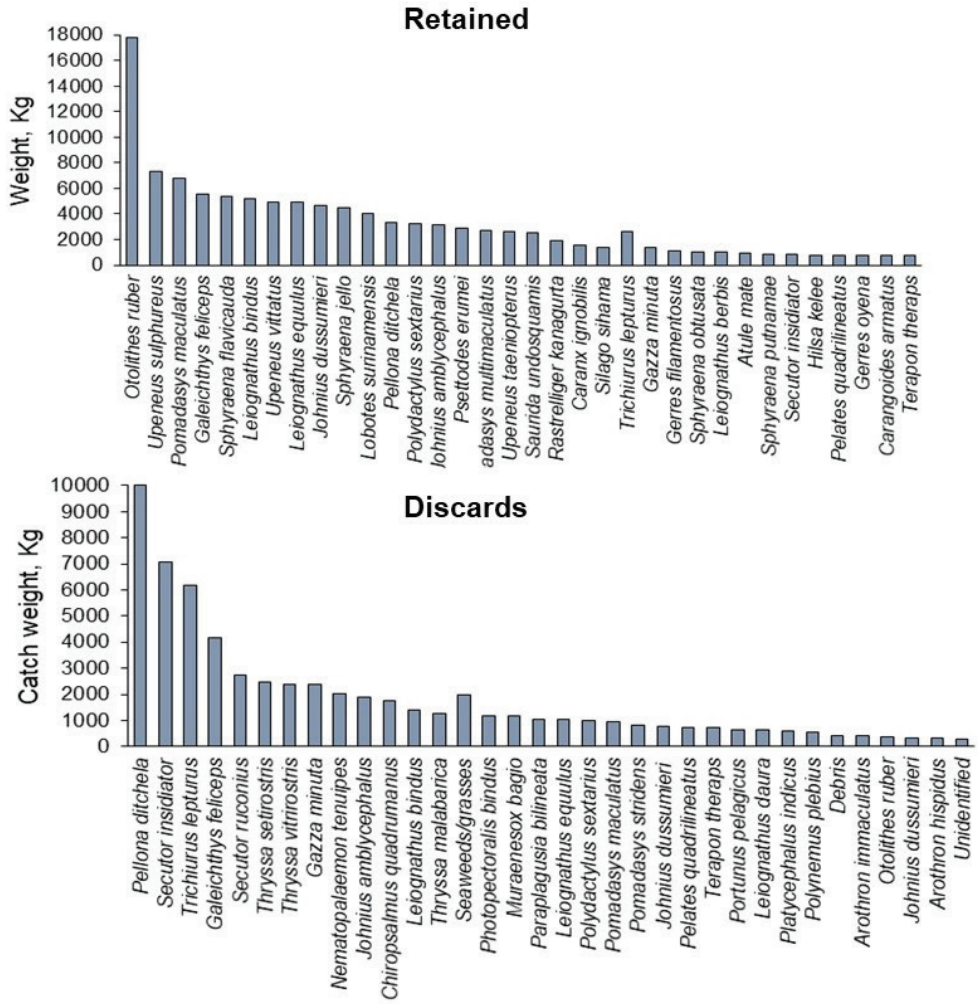
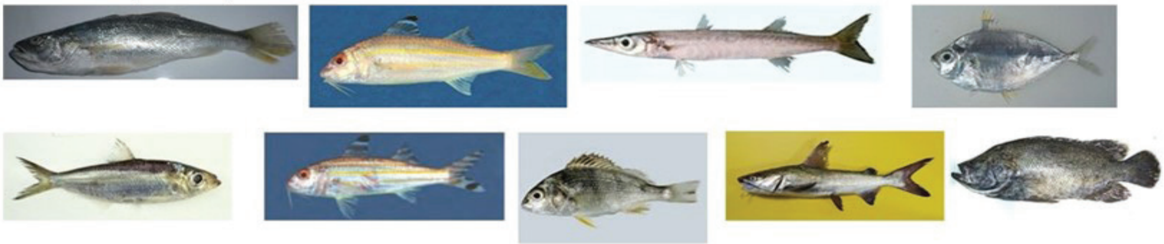


Figure 5.6.4 : The top 35 retained and discarded bycatch species captured in the shallow water prawn trawl fishery of Kenya within the Malindi-Ungwana Bay

Retained bycatch species



Top row from left: *Otolithes ruber, Upeneus sulphureus,* and *Sphyraena flavicauda*

Bottom row from left*: Leiognathus bindus, Pellona ditchela, Upeneus vittatus, Pomadasys maculatus, Galeichthys feliceps and Lobotes surinamensis*

Discarded bycatch species

From left: *Pellona ditchela, Secutor insidiator, Trichurus lepturus, Thryssa setirostris, Secutor ruconius* and *Gazza minuta*

Plate 5.6.5: Photos of some of the top retained and discarded bycatch finfish species caught in the shallow water prawn trawl fishery at the Kenya coast

the harvestable fishery resource found between 100 m and 600 m depth can sustain a long term fishery. Observers were deployed on the vessels to collect catch and biological data of the crustacean catch as well as the bycatch. Mapping of the fishing grounds during 2016 show the vessels fish between latitudes 320'S and 2°30'S and longitudes 40°10'N and 41°00'N (Fig. 5.6.5). Five fishing trips were covered for the deep-water trawling trials during the November 2016 – January 2017 period. Most of the fishing effort is concentrated off Malindi and Ungwana Bay.

Catch and catch composition

The results show that out of the 58133.1Kg of sampled catch that was examined, 42745.3Kg (73.5%) was retained and 15387.8Kg (26.5%) was discarded. Out of the sampled catch, 23663.8Kg (41%) was retained finfish, 13962Kg (24%) was retained crustaceans, 3785.6Kg (6.5%) was retained molluscs, and 1333.8Kg was retained sharks and rays (Table 5.6.3). The discards consisting of mixed discarded finfishes, crustaceans, sharks, rays, molluscs and sponges.

The total catch per trawl ranged between 109.6Kg and 292.2Kg. Discards from each trawl varied between 38.7 - 101.1Kg while the retained finfish was between 33.8 - 113.1Kg. The highest catch from one trawl for the target crustaceans was 72.7Kg for the lobsters and the lowest was 0.5Kg for crabs. During the 5 deep water trial trawl observations, 11Mt of lobsters was caught. The species of lobsters included the Natal spiny lobster *Palinurus delagoae* (48%) Banded

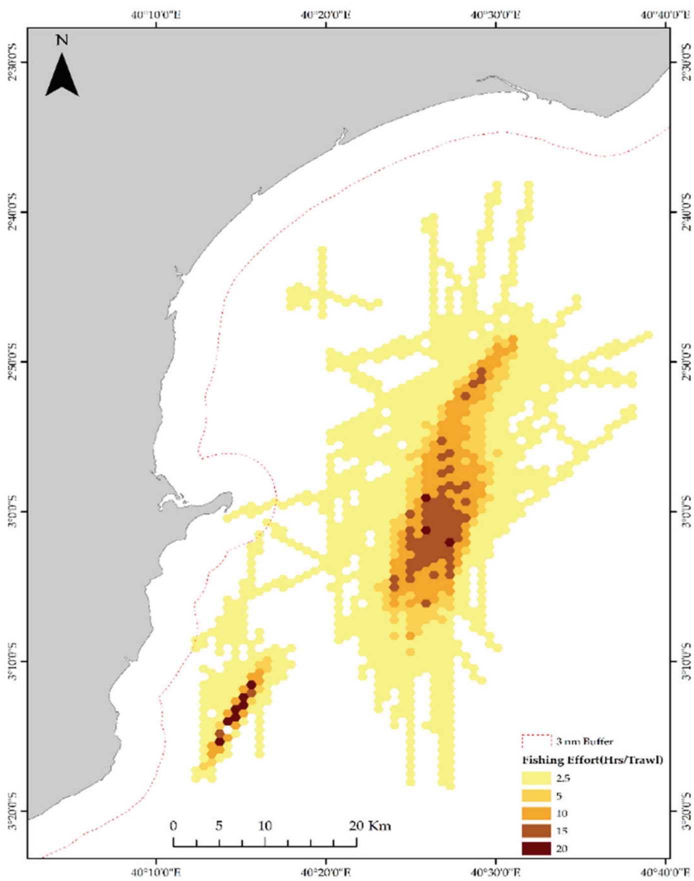


Figure 5.6.5: The distribution of the total fishing effort (number of hours per trawl) within the Malindi-Ungwana Bay during the deep-water fishing trials

whip lobster *Puerulus angulatus* (46%) African spear lobster *Linuparus somniosus* (0.6%) and African lobster *Metanephrops mozambicus* (0.4%). Nine species of deep water prawn species were identified including *Penaeus marginatus, Penaeopsis balssi, Parapenaeus investigatoris, Plesionika edwardsii, Acanthephyra* spp., *Heterocarpus woodmasoni, Parapenaeus fissurus, Solenocera algoensis* and *Aristaeomorpha foliacea*. The first four species accounted for up to 95% of the total prawn catch.

The Marginated shrimp *Penaeus marginatus* was the most common making up 503.7Kg (65.7%) followed by the Scythe shrimp *Penaeopsis balssi* with 105.8Kg (13.8%). Approximately 2Mt of *Chaceon macphersoni* (the main commercial crab), 1.6Mt of the cuttlefish *Sepia acuminate*, 1.3Mt of *Sepia officinalis vermiculata* and 0.7Mt of the squid *Uroteuthis (Photololigo) duvaucelii* were also caught during the observations. Sixty three finfish species were identified in the retained catch dominated by Rushtooth lizardfish *Saurida undosquamis*, the Spotted greeneye *Chlorophthalmus punctatus* and Blackmouth splitfin *Synagrops japonicas*, and up to 126 species of finfish and other organisms were discarded (Fig. 5.6.7). The top 35 of the species discarded constituted approximately 90% of all discarded bycatch).

5.6.5 Fisheries observers and management

The shallow water prawn fishing effort and catches have been found to continue increasing over the last 6 years from 2011 to 2017, indicating that the fishing effort is within sustainable limit. However, the prawn catches appear to be reaching a maxima with the current fishing effort. Most of the bycatch is landed and supplements artisanal catches and supports small scale fish businesses in the urban centers particularly in Mombasa. The results from the deep water trawl fishing trials indicate the viability of exploiting deep water resources available to trawl fishing include demersal finfishes (40%), commercial crustaceans (24%) and commercial molluscs at 6.5 % of the total catch. The data collected by Fisheries Observer Programme provides a basis for the annual review of the shallow water semi-industrial prawn fishery by providing the progressive effect of fishing on the target resources as well as the ecosystem. The Observer Programme is also expected to support the management of the fishing effort within the deep water trawl fishery of Kenya. The Programme is therefore a key activity in marine fisheries research and plays a significant role in the management of the fisheries resources.

Table 5.6.3: The distribution of deepwater trawl catches (Kg) by depth during the 2016 observer monitoring period

Taxon	Depth profiles, metres					
	< 200	200 - 250	250 - 300	300 - 350	300 - 350	Total
Cnidarians			3.1			3.1
Crabs	1671.1	543.7	2448.6	86.0	4.0	4753.4
Echinoderms	3.4	2.8	1329.3	32.7		1368.2
Finfishes	451.5	103.7	31608.8	1273.8		33437.9
Lobsters		38.4	10568.2	339.8	9.3	10955.8
Mantis shrimp			28.0			28.0
Molluscs	84.4	17.2	3814.0	173.2		4088.9
Other crustaceans			0.7			0.7
Porifera			2.0			2.0
Prawns	311.3	29.9	435.3	12.1	2.7	791.3
Rays	157.6		533.5			691.2
Shark	72.4	12.3	1826.3	98.9		2009.9
Unknown			2.9			2.9
Total	2751.7	748.0	52600.9	2016.5	16.0	58133.1

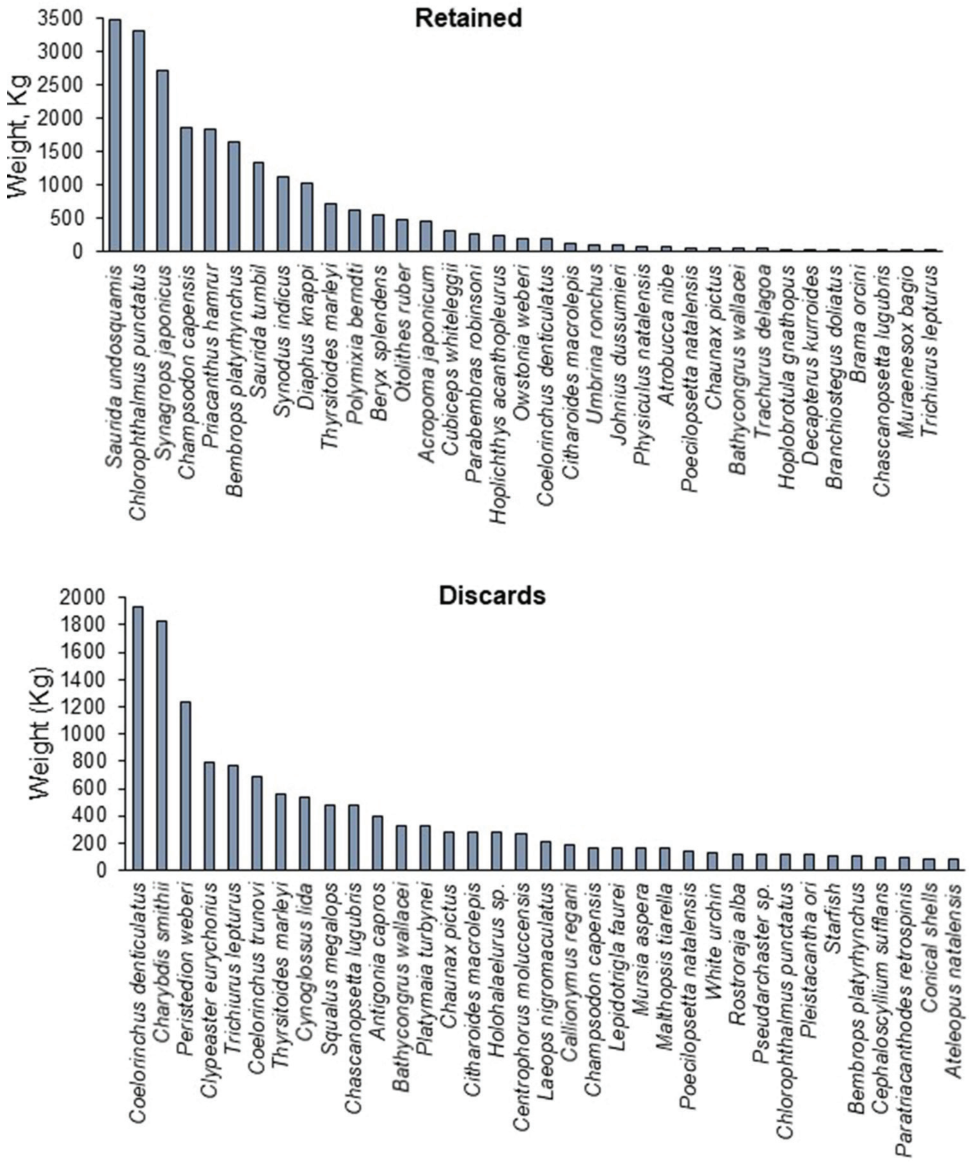


Figure 5.6.6: The species composition retained and discarded catches during the 2016/2017 deep water crustacean trawling trials off the Malindi-Ungwana Bay

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5.7 Biodiversity: Marine Mammal Sightings

Gladys Okemwa, Nina Wambiji and Renison Ruwa

5.7.1 Introduction

The Western Indian Ocean region hosts diverse vulnerable species of marine megafauna including whales, dolphins, dugongs, sea turtles, sharks and rays (Van der Elst and Everett, 2015). Most of the megafuana populations in the region and globally are undergoing enormous declines due to incidental mortalities and direct exploitation in fisheries (Kizka *et al.*, 2008). However information on their population dynamics and movement patterns is poorly understood (De Lestang, 1993). This information is vital in detecting long-term changes in distribution and habitat use, especially due to the effects of anthropogenic activities.

Most of the species migrating through the WIO region face threats from operational interactions with fisheries resulting in incidental bycatch, ghost fishing in abandoned fishing gears, and collisions with vessels (de Boer *et al*., 2002; SWIOFP, 2012). Pollution, particularly marine debris including ingestion of plastics is another emerging threat (de Boer *et al*., 2002). However, inadequate scientific knowledge and a lack of capacity remains a handicap for most of the regions nations from undertaking assessments in the EEZ regions of their seas (Van der Elst and Everett, 2015). Obtaining such data presents a major challenge because they are generally elusive, occur at low densities and range over wide and distant spatial scales which are difficult to access and monitor on a regular basis. Consequently, the paucity of information on these charismatic species poses a major challenge to their conservation.

5.7.2 Species composition and distribution

A total of 37 marine mammal species within the WIO region including 32 cetacean species, 1 sirenian (the dugong) and 4 pinnipeds) have been reported (SWIOFP, 2012). At least 25 species of cetaceans are known to occur in the Eastern African Region, including six baleen whales, 10 toothed whales and nine dolphins (De Lestang, 1993). Records of marine mammal sightings have increased significantly since the establishment of the Kenya Marine Mammal Network (KMMN). Of the 681 marine mammal sightings recorded during 2011 – 2013 (Table 5.7.1), dolphins represented 98% of the sightings, with the most frequently sighted species being the Indo-Pacific Bottlenose dolphin *Tursiops truncates* (59%) and the spinner dolphin *Stenella longistris* (29%). The sightings represented 12 cetacean species and a dugong. Large whale species were also documented including *Megaptera novaeangliae*, *Orcinus orca*, *Physeter macrocephalus*, *Balaenoptera acutorostrata* and *Peponocephala electra* (Table 5.7.1).

Spatially, dolphins were most frequently sighted at the southcoast in Shimoni (96 sightings), and at Malindi (52 sightings) in the northcoast. Other areas included Kilifi (5 sightings), Lamu (2 sightings), Mombasa (1 sighting), and Tana River (1 sighting). The frequency of sightings was also highly seasonal,

Table 5.7.1: Summary of marine mammal sightings reported by the Kenya Marine Mammal Network (2011-2013)

Common name	Scientific name	No. sighted	Relative abundance (%)
Bottlenose dolphin	*Tursiops aduncus*	384	56.4
Humpback whale	*Megaptera novaeangliae*	198	29.1
Spinner dolphin	*Stenella longistris*	32	4.7
Humpback dolphin	*Sousa plumbea*	27	4
Unidentified dolphins		26	3.8
Pilot whales	*Globicephala macrorhynchus*	5	0.7
Orcas	*Orcinus orca*	3	0.4
Dwarf Minke whale	*Balaenoptera acutorostrata*	2	0.3
Common dolphin	*Delphinus capensis*	1	0.1
Bryde's Whale	*Balaenoptera edeni*	1	0.1
Sperm whale	*Physeter macrocephalus*	1	0.1
Unidentified whale		1	0.1
Dugong	*Dugong dugon*		0
Grand Total		**681**	

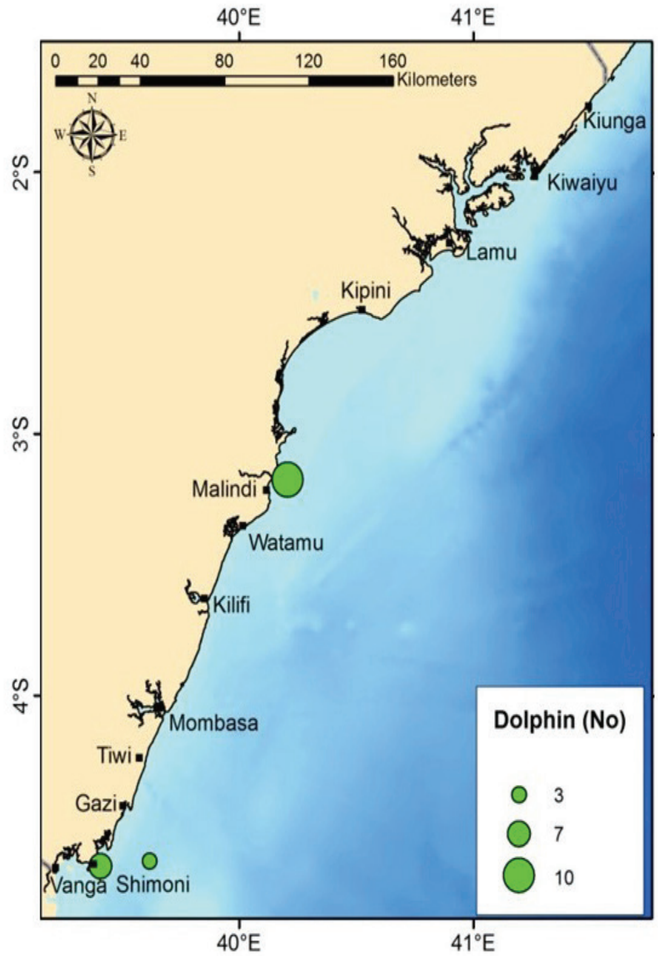

Figure 5.7.1: The distribution of opportunistic cetacean sightings (in absolute numbers) onboard RV Mtafiti in absolute numbers during surveys conducted within Kenya's territorial waters

for example humpback whales are frequently sighted between the months of July to October coinciding with the peak breeding and calving periods. The reported distribution patterns are also consistent with the results of the opportunistic sightings onboard RV Mtafiti which show the territorial waters off Shimoni area and the Kilifi-Watamu to host relatively higher numbers compared to other areas (Fig 5.7.1).

5.7.3 Discussion and conclusion

The inshore waters off Shimoni and Watamu are known hotspots for marine mammal biodiversity along the Kenya coast. The Kisite Mpunguti area area in Shimoni supports the largest dolphin watching ecotourism venture in Kenya, and has increasingly become a popular tourist attraction (Perez-Jorge *et al.*, 2016). The dolphin population in the area appears to be discrete, consisting of about 70 resident individuals of Indo-Pacific bottlenose which have been identified using photo identification methods through collaborative monitoring efforts. It is likely that hydrographic and bathymetric features in the area play an important role in influencing fine-scale distribution patterns (Ingram and Rogan, 2002). Mapping of the critical habitats of these vulnerable species is is an important element to enhancing conservation.

In addition, the economic benefits from dolphin watching ecotourism provides an incentive for their conservation. Improved knowledge of their occurrence in other areas of the Kenya coast will help to identify other potential areas to enhance blue economy growth in the tourism sector. However, such expansion must be done in an eco-friendly manner to ensure that any negative impacts such as noise pollution and harassment which is documented to affect swimming

Plate 5.7.1: A pod of dolphins sighted in Shimoni, south coast of Kenya onboard RV Mtafiti (Photo Credit: Nina Wambiji)

behaviour and group formation by disrupting co-operative behaviour and communication between individuals. Moreover, the reproductive success can also be affected over the long term (Perez-Jorge *et al*., 2016).

The platform of opportunity for marine mammal sightings provided by RV Mtafiti has facilitated information on occurrence and distribution patterns in the offshore/EEZ waters. However, the low number of sightings may be due to the opportunistic nature of the surveys which limits sampling effort. Furthermore, tracking of sighted animals is not possible due to the size of the vessel and the fixed cruise tracks making it difficult to accurately identify them to species.

Overall, the results indicate that the coastal waters of Kenya support a high biodiversity of marine megafauna providing important breeding, feeding and migratory grounds. Such information may be particularly useful in informing Environmental Impact Assessments to demarcate potentially high risk areas of anthropogenic interactions. It will be important in future to relate the recorded occurrences with oceanographic conditions, particularly sea surface temperature and depth. Other research recommendations that can be implemented using RV Mtafiti include within the hotspot areas include: monitoring of fishing effort, bycatch, and water quality as well as conducting fish stock assessment surveys.

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5.8 Monitoring of HABs in the Kenyan Marine Waters

Eric Okuku, Linet Kiteresi, Alex Fulanda and Mary Mkonu

5.8.1 Introduction

The term 'Harmful Algal Bloom' or HAB is used to describe visible blooms of algae that kill fish, make shellfish poisonous, and cause numerous other problems in the marine coastal waters (Hoagland *et al.*, 2002). HABs occur when algal cells proliferate to concentrations sufficient to cause harm to other species, as a result either of their production of toxins or their physical shape and/or accumulated biomass (Anderson *et al*., 2002; Hallett *et al*., 2015). Such blooms occur worldwide and in a range of aquatic environments, including freshwater lakes, rivers, estuaries (Burkholder and Glasgow, 2001), coastal and oceanic marine waters (Anderson *et al*., 2008; Fu *et al*., 2012). There is currently a worldwide increase in the frequency and magnitude of HABs that has been attributed to changes in oceanic climate, increased coastal eutrophication and enhanced long-distance dispersal in ballast water (Landsberg, 2002; Heisler *et al*., 2008; Rabalais *et al*., 2009).

The occurrence of HABs can have a wide range of deleterious impacts on aquatic biotic communities ranging from the micro-scale to the ecosystem scale (Landsberg, 2002; Graneli and Turner, 2008). Their effects depend on the species involved and prevailing environmental conditions (Sunda *et al*., 2006). Some of the effects include clogging of gills (Graneli and Turner, 2008), poison by water-borne toxins and cellular damage caused by reactive oxygen species (Cembella *et al*., 2002; Kim *et al*., 2002), localized anoxia (Anderson *et al*., 2002) and increased vulnerability to predation (Vogelbein *et al*., 2002). Responses to the effects of HABs typically vary among species; thus, the interpretations of the effects (particularly those beyond the short term) are often complex (Hallet *et al*., 2015). HABs are thus likely to affect a much wider variety of taxa than other environmental disturbances given the variable mechanisms by which they cause damage and the differences in the magnitude of bloom events (Pratchett *et al*., 2008).

The Indian Ocean hosts one of the largest phytoplankton blooms among the tropical oceans. It is particularly more productive, with average primary productivity estimated at about twice the global average (Ryther *et al*., 1966). Despite its importance, the Indian Ocean remains one of the most under studied and least understood of the world's ocean basins (Hood *et al*., 2008). Kenya coastal waters are characterized by the movement of the Inter-Tropical Convergence Zone (ITCZ) driven by the seasonal monsoon winds that causes upwelling of nutrients which is suspected to be responsible for high fisheries productivity in the northern coast of Kenya. Generally, as primary productivity increases, the risk of occurrence of HABs incidences is expected to be significant. KMFRI contributes towards a global monitoring and management programme on HABs coordinated by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO). As part of the monitoring programme, this assessment presents preliminary findings of a baseline survey on the occurrence and distribution of potential HAB taxa within the Kenyan territorial and EEZ waters undertaken onboard RV Mtafiti.

5.8.2 Survey results

The highest abundance of potentially toxin producing taxa (mean: 142.26; range: 1.67-9862.50 cells l^{-1} was recorded in the EEZ (off Kwale, Malindi, Lamu and Mombasa Counties), compared to the Kenya territorial waters with a means of 7.06 cells l^{-1} and a range of 1.00-75.00 cells/L (Table 5.8.1). Within the territorial waters, the highest number of HAB taxa was recorded off Lamu and Kilifi, while the highest abundances was recorded off Lamu and Kwale (Table 5.8.2).

The list of the HABs taxa identified in the territorial and EEZ waters and their abundance is presented in Annexes IV and V. A total of 20 potential HAB species were encountered in Kenya's territorial waters dominated by *Anabaena spp.* off Lamu (Annex IV), whereas a total of 32 taxa were encountered in the EEZ (Annex V). The highest abundance of HABs taxa was also observed in the EEZ off Mombasa with means of 1437.20 and a range of 37.50 - 10037.50 cells/L due to high cell densities of *Pseudo-nitzschia spp* which were most abundant overall (Annex V). The high abundance of this species could be due to ballast water discharges from vessels at the Mombasa Port, in addition to nutrient sources from urban discharges as reported by Okuku *et al.*, (2011).

Cyanophycea were dominant at the Lamu and Malindi area (Annex V). Most Cyanophycea are known to occur in freshwater systems and typically respond to increasing temperatures as they thrive in warm waters (O'Neil *et al.*, 2012) and may thus be favoured by decreasing salinities (Engström-Öst *et al.*, 2011). The Kenya territorial waters receive considerable amount of freshwater and nutrients inputs from Galana-Sabaki and Tana Rivers rivers which may favor the proliferation of Cyanophycea.

Blooms of highly toxic algal cells can cause problems even at low (and essentially invisible) cell concentrations (Anderson *et al.*, 2012). Bloom forming taxa recorded off Mombasa in the EEZ comprised of *Chaetoceros spp.* (range: 2350-18250 cells/L), *Guirnadia strata* (mean: 2750 cells/L), *Guirnadia spp.* (range: 2325-2662.5 cells/L), *Leptocylindricus spp.* (mean: 2062.5 cells/L), *Protoperidinium spp.* (range: 2662.5 cells/L), *Rhizosolenia spp.* (range: 2387.5-9812.5 cells/L) and *Thalassionema nitzschoides* (range: 3625-4187.5 cells/L). *Chaetoceros spp.* which was also abundant during the survey are known to cause mucus production and damage by their spiny setae. *Gyrodinium spp.*, which was recorded in low and high cell densities (higher than 10^7 cells/L) in the EEZ waters, is known to kill fish and benthic fauna as reported elsewhere (Andersen, 1996). On the contrary, *Dinophysis spp.*, was encountered in low densities in the territorial and EEZ waters, is capable of being harmful even at low cell densities of ~50 cells/L (Kat, 1983; Marcello-Le Abut *et al.*, 2001).

Eutraptiella sp. and *Ceratium sp.* However, this survey recorded low cell densities of these taxa (Annex IV and V). *Thalassiosira sp.* and *Dictyocha sp.*, which occurred in low cell densities, are also known to stimulate excess mucus production in fish gills when present in dense concentrations and may lead to fish deaths (UNESCO, 2004).

Chrysochromulina spp. which are known as potentially toxic nanoflagellates and can efficiently utilize the low nutrient levels (Lekve *et al.*, 2006) were recorded in EEZ off Mombasa and North coast at low cell densities. *Gyrodinium spp.*, which was recorded in low and high cell densities (higher than 10^7 cells/L) in the EEZ waters, is known to kill fish and benthic fauna as reported elsewhere (Andersen, 1996). These taxa have the potential to form toxic blooms when present in high densities; however, the toxicity threshold for each taxon may differ due to the species specific physicochemical characteristics that may trigger proliferation).

Potential human impacts of HABs on the Kenyan marine waters

Some HAB species produce potent toxins that accumulate in shellfish and fish resulting in poisoning syndromes in human consumers which include paralytic, diarrhetic, amnesic, and neurotoxic shellfish poisoning (PSP, DSP, ASP, and NSP, respectively) (Hoagland *et al.*, 2002). The species *Pseudo-nitzschia spp.*, *Nitzschia spp.*, *Alexandrium spp.*, *Dinophysis spp.*, *Gambierdiscus spp.*, *Ostreopsis spp.* and *Prorocentrum spp.* are known to produce toxins that accumulate to specific syndromes (Table 5.8.3) have been previously encountered in the Kenyan waters (Kiteresi *et al.*, 2013), and were

Algal blooms occurring in Kenya's marine waters have been reported to cause discolouration of the water and massive fish die offs due to anoxic conditions resulting from high cell densities of *Skeletonema sp.*, *Noctiluca scintillans*,

Table 5.8.1: Therange and mean abundance (Cell l^{-1}) of HABs taxa within various stations in territorial and EEZ waters of the Kenayna Coast

		Abundance		
Zone	Area	Mean	Minimum	Maximum
Territorial	Kwale	31.8	12.5	51.0
	Kilifi	20.0	5.0	45.0
	Malindi	12.9	5.0	20.0
	Lamu	51.3	22.5	105.0
EEZ	Kilifi - Malindi	26.7	5.0	72.5
	Mombasa	1437.2	37.5	10037.5
	Kwale	9.3	1.7	102.5

Table 5.8.2: Mean abundance of HABs taxa (Cells l^{-1}) within various station in territorial (Terr.) and EEZ waters of the Kenyan coast

Zone	Area	Dinoflagellates	Diatoms	Cyanophyceae	Flagellates
Territorial	Kwale	-	2.5	-	-
	Kilifi	6.9	7.9	-	-
	Malindi	4.8	3.3	20	-
	Lamu	6.2	6.2	40	-
EEZ	Kilifi - Malindi	7.2	7.8	2.5	4.17
	Mombasa	27.8	878.8	15.3	15
	Kwale	5.3	3.2	7.5	-

also encountered during the RV Mtafiti surveys.

PSP is produced by saxitoxins which lead to gastrointestinal and neurological symptoms such as nausea, vomiting, diarrhea, tingling or numbness around lips with gradual and more severe paralysis, respiratory difficulty and eventual death through respiratory paralysis. *Anabaena sp.* and *Nodularia spumigena* are known to release the neurotoxins microcystin and nodularin upon cell death or lysis (Pattanaik *et al*., 2010). *N. spumigena* is capable of producing significant amounts of nodularin, (a liver toxin) which can cause skin, eye and throat irritation and also act as a tumour promoter (WHO, 2003). The wide distribution of *Alexandrium sp.* and *Dinophysis sp.* observed in this survey could be explained by the fact that these taxa are less affected by coastal nutrient enrichments (UNESCO, 2004). Worth noting is that their toxicity is triggered in multispecific interactions among *Chaetoceros spp.*, *Pseudo-nitzschia spp.* as well as *Dinophysis spp.* or *Alexandrium spp* (Lassus *et al*., 2016).

DSP is characterized by gastrointestinal symptoms (nausea, diarrhea, and vomiting, abdominal pain) which follow chronic exposure that may evolve into digestive system tumors. ASP can lead to loss of short term memory, accompanied by gastrointestinal and neurological symptoms. NSP is mainly caused by bloom forming cyanobacteria (or blue-green algae). Ciguatera Fish Poisoning (CFP) is due to ciguatoxin, and together with tetrodotoxin, is the only other toxin that is exclusively transmitted to humans through consumption of fish causing symptoms of diarrhea, abdominal pain, nausea, vomiting, and other neurological symptoms.

5.8.3 Discussion and conclusion

Global concerns over the ecosystem and human health consequences of HABs has heightened the need for scientific information and regulatory attention (Anderson *et al*., 2012). Regionally in the WIO, the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) supports efforts towards monitoring and management of HABs (Ruwa and Rice, 2016). However, the data remains inadequate to generate trends over time for predicting potential occurrence of blooms and associated risks.

The results of this inventory provides new and valuable information on the presence and distribution of potential HAB species in Kenya's territorial and EEZ waters. The higher cell densities in the EEZ compared to territorial waters are likely influenced by hydrodynamics including upwelling. Even though most of the HAB species were available in low cells densities, the potential impacts particularly from toxin causing taxa remain a likely threat. Future research and monitoring efforts should focus on establishing a sustained long-term routine program to monitor, detect and predict bloom events within the terrestrial and EEZ waters. There is also a need to develop a national contingency plan to ensure appropriate and rapid response to HAB events. Targeted outreach and education on HABs, especially among the fishing community and commercial industry should also be prioritized.

Table 5.8.3: Some potential HAB species documented along Kenya's coastal waters and the syndromes that they cause in human consumers

Poisoning Syndrome	Main toxin	Causative HAB species
Paralytic shellfish poisoning (PSP)	Saxitoxin	*Alexandrium spp.; Gymnodinium spp.; Anabaena spp; Pyrodinium spp*
Diarrhetic shellfish poisoning (DSP)	Okadaic acid	*Prorocentrum spp.; Dinophysis spp*
Amnesic shellfish poisoning (ASP)	Domoic acid	*Pseudo-Nitzschia spp.; Nitzschia spp*
Neurotoxic shellfish poisoning (NSP)	Ciguatoxin, Maiotoxin	*Gambierdiscus spp.; Amphidinium spp*
	Palytoxin	*Ostreopsis spp*

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5.9 Microplastic pollution: documented evidence in Kenya's marine waters

5.9 Microplastic pollution: documented evidence in Kenya's marine waters

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5.9.1 Introduction

Pollution of coastal and oceanic waters by plastics represents an increasing concern for both science and society, especially the accumulation of plastic fragments in the environment and their absorption through ingestion by organisms. Plastics constituent 60-80% of all marine debris and constitute about 90% of floating debris worldwide (Frere *et al*. 2017). The study of the occurrence and composition of microplastics in the surface water and evidence of entry into the marine food chain through ingestion by zooplankton has become an important part of marine pollution studies.

Plastic is a general term that refers to a family of organic polymers derived from petroleum sources, including polyvinylchloride (PVC), nylon, polyethylene (PE), polystyrene (PS), and polypropylene (PP), with common plastic polymers being PP, PE, low density polyethylene (LDPE), and polyacrylates. Plastic polymers that are positively buoyant in seawater and are retained at the sea surface, where they are dispersed before becoming entrapped in areas of low circulation, and finally sink after entanglement and biofouling.

The quantity of plastic in the ocean and of volumes entering the ocean from waste generated on land is unknown. The used and production patterns suggest that quantities of plastics in aquatic environments will continue to increase over time, and concentrated in around densely populated regions (Clark *et al*., 2016). The plastics enter the sea via beaches, rivers, stormwater runoff, agricultural and industrial sewage, wastewater discharge or transport by wind while shipping and other maritime activities contribute through the materials lost by commercial and recreational fishing, and debris dumped by commercial and cruise ships. Various studies have shown that microplastics are now distributed in all oceans, occurring on shorelines, in sediments and in surface waters even in remote locations such as the arctic and at all depths (Cincinelli *et al*. 2017).

When plastic waste is exposed to UV radiation and mechanical forces, it slowly breaks down into smaller fragments, known as secondary microplastics, of irregular shapes and sizes, which are the main form of plastic debris found in the environment. Microplastics can be ingested by a wide range of marine organisms such as filter-feeders or higher-level predators, leading to negative impacts at the base of the marine food chain. (Clark *et al.* 2016). Microplastics are found in high abundance in surface waters, where zooplankton predominantly inhabit when feeding. Zooplankton are a vital source of food for secondary consumers (e.g. fish, cetaceans) and represent a route via which microplastics enter the food web, posing a risk to secondary producers and apex predators and potentially, to human health (Steer *et al*. 2017).

In order to effectively address microplastic pollution in the marine environment, information on the abundance, distribution and composition of microplastics is required. The problem of plastic pollution on the environment in Kenya has been recognised leading to a ban on the use of plastic carrier bags in 2017. However, the amount of plastic used and released into the marine environment in Kenya is not known and the occurrence and ingestion of microplastics by zooplankton in the West Indian Ocean is unknown. RV Mtafiti surveys provide the first report on the occurrence, abundance and composition of waterborne microplastics and evidence of ingestion by zooplankton in Kenya's marine environment.

5.9.2 Sampling methodologies

The samples were collected from 11 georeferenced sites located in the central part of Kenya's Exclusive Economic Zone (EEZ) shown in Fig. 5.9.1. The field work was conducted on board the RV Mtafiti during the northeast monsoon between 6th and 21st February 2017. One sample was collected at each site using a 15 litre stainless steel bucket to collect a total volume of 120 l of sea water, which was sieved directly through a 250 µm stainless steel mesh. The samples were then transferred into glass jars containing 70% ethanol for preservation and maintain the colour of the organisms, to facilitate identification of microplastics.

A zooplankton sample was collected from each station by towing horizontally a zooplankton net

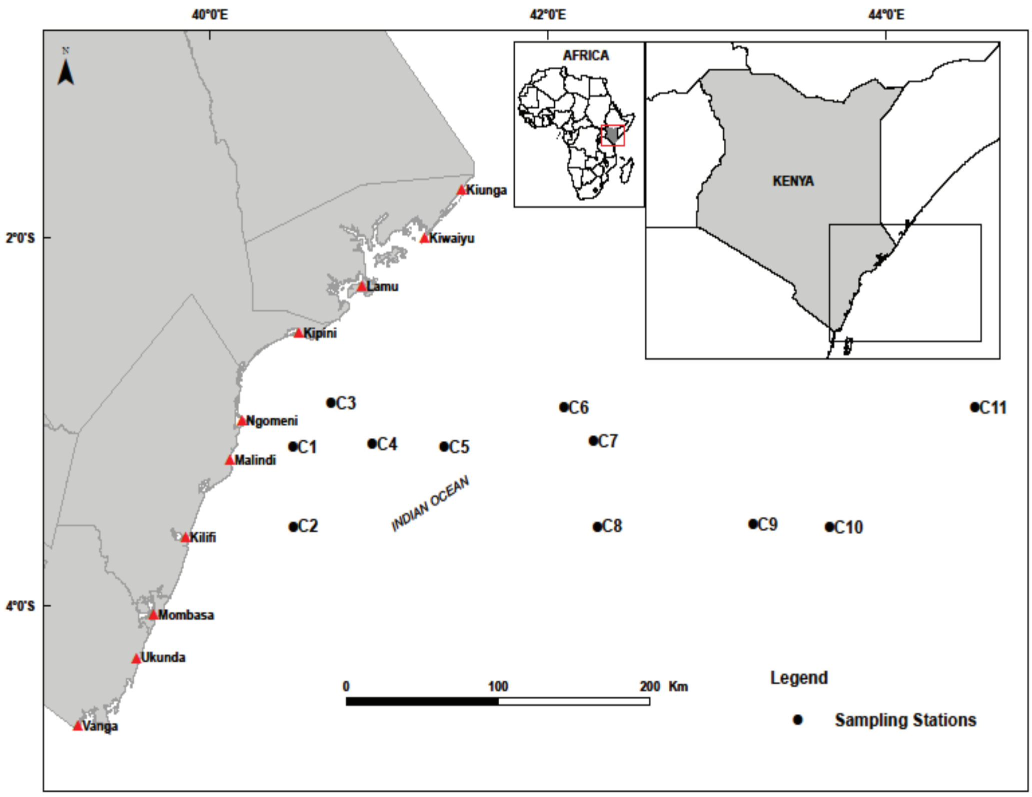

Figure 5.9.1: Map showing the study area with sampling stations. Red triangles indicate major coastal towns

with a 500µm mesh and with a General Oceanics® flow meter attached to the mouth at a speed of 0.5-1.8 knots for a period of between 20 and 30 minutes. The net was retrieved and rinsed with seawater to collect all zooplankton samples which was transferred into glass jars containing 70% ethanol. The samples were transported to the laboratory for further processing and analysis. Sampling locations and environmental parameters including wind direction and speed, salinity, sea-surface temperature (SST) and pH were recorded in situ.

In the laboratory, surface water microplastics were extracted by filtering samples through 0.7µm GF/F Whatman Filter paper using a Pall filtration unit connected to a Rocker 400 vacuum pump. The filters were dried in a vertical stainless steel laminar flow hood (Crichton *et al*. 2017) and then placed in glass petri dishes and stored at 20°C until analysed. The individual dried filters were visually inspected under a dissecting microscope at ×20 magnification to count the microplastic particles and categorise them based on morphological characteristics, such as shape (filament/fibre, fragment, pellet, granule, film or foam), colour (black, blue, green, brown, orange, pink, red, transparent, white or yellow) and size according to Castillo *et al*. (2016). Photograph of the particles and the sizes were measured using Optika Vision Lite 2.1 and MIPro Standard 1.2 software. A subsample was selected and analysed for polymer type using ALPHA platinum Attenuated Total Reflectance – Fourier transform infrared (ATR-FTIR).

Zooplankton samples were identified and counted under a dissecting microscope. During the process, 10 individuals from the four groups: Chaetognatha, Copepoda, Amphipoda and fish larvae were selected. The individuals were examined under the microscope, and any adhering microplastic particles were removed. Digestion of the zooplankton groups was performed according to Castillo *et al*. (2016) to extract the ingested microplastics. After digestion, the extracted microplastics were quantified as particles per individual group.

Nine surface water microplastic particles, seven in the size range of 1.1-1.7mm and two in the range of 2.3-2.4mm, and four (range 0.6-1.6mm) from the ingested particles were subsampled and analysed to determine the types of polymers using ATR-FTIR spectroscopy from Bruker, Germany according to Kanhai *et al*. (2016). The surface water microplastic particles were identified and categorised into four common shapes (fibres/filaments, fragments, granules and foams). The particles were clamped onto the ATR diamond crystal, which consisted of 24 scans in the spectral wave number range of 4000 to 400 cm^{-1} at a spectral resolution of 4 cm^{-1}. Bruker's Opus 7.5 spectroscopy software was used to process and evaluate all spectra. Identification involved the comparison of the absorbance spectra of the samples with reference spectrum in the Bruker Optics ATR Polymer library. Quality control to avoid contamination of the sample with microplatics from the work environment was conducted according to Kanhai *et al*. (2016), Cincinelli *et al*. (2017) and Crichton *et al*. (2017).

Table 5.9.1: The rate of ingestion (%) of microplastics particles by zooplankton groups

Zooplankton group	Percent ingestion rate (%)
Chaetognatha	46
Copepoda	33
Amphipoda	22
Fish larvae	16

5.9.3 Survey results

Microplastics were detected at all the sampling stations, with a total of 149 microplastic particles being confirmed. Filaments contributed 76%, followed by fragments (12%), granules and foams (collectively 12%) (Plate 5.9.1). The dominant shapes in water were filamentous, which were mostly coiled (and elastic when stretched), only 29 of the 149 particles were measured. The dominant size category was in the range 0.25–1.0mm (n = 18), followed by 1.1–1.7mm (n = 7) and 2.3–2.4mm (n = 4). The sizes were all <5mm in length confirming them as microplastics according to the definition of GESAMP (2016). Throughout the 11 sampling stations, 51% of particles (n = 75) were white and 26% (n = 39) were black, while the remaining 23% (n = 34) collectively comprised blue, brown, green, yellow, red and

Plate 5.9.1: Microplastic filaments obtained from digested zooplankton in Kenya's marine water (x40 magnification)

pink. Filaments as a category of microplastics are generally more discernible than other categories. Thus, they are usually encountered in samples more than other categories of microplastics (Kanhai *et al*. 2016). The high occurrence of filaments originate from abrasion and weathering of larger plastic or derived from local fishing gear (nets, lines), ropes and clothing (Kanhai *et al*. 2016; Cincinelli *et al*. 2017). White is the predominant colour, an indication that the source polymer type could have been PE, as suggested by Rodriguez-Seijo and Pereira (2017).

Results of the Pearson Correlation test showed the five variables Longitude, Latitude, SST, Salinity and Wind Direction were found to have significant correlations with microplastics abundance in Kenya's EEZ in the following descending order: Longitude > Wind Direction > SST > Latitude > Salinity . The relationship between environmental factors and the abundance of microplastics is a result of vertical mixing and stratification. The increase in the abundance of microplastics with distance from shore could likely be due to the influence of wind-driven transport of microplastics from inshore areas.

The results generally show an increase in microplastics abundance in an offshore direction (Fig. 5.9.2). Microplastics abundance varied across the sampling stations with a range of 33.3-275 particles m^{-3} and with an average abundance of 110 particles m^{-3}. The highest abundance was recorded at station C10 (275 particles m^{-3}), followed by C8 (183 particles m^{-3}), with the lowest being recorded at stations C1 and C5 (33 particles m^{-3}). Microplastics abundance increased with distance from land, contrary to the expectation of a higher abundance closer to the shore (Kang, *et al*., 2015). As noted by Nel and Froneman (2015), microplastics are distributed by water circulation and ocean currents over both short and long distances. This indicates that the observed concentrations may also be originating from elsewhere. Comparing the results with other regions, microplastics abundance in this study appears to be higher than abundance

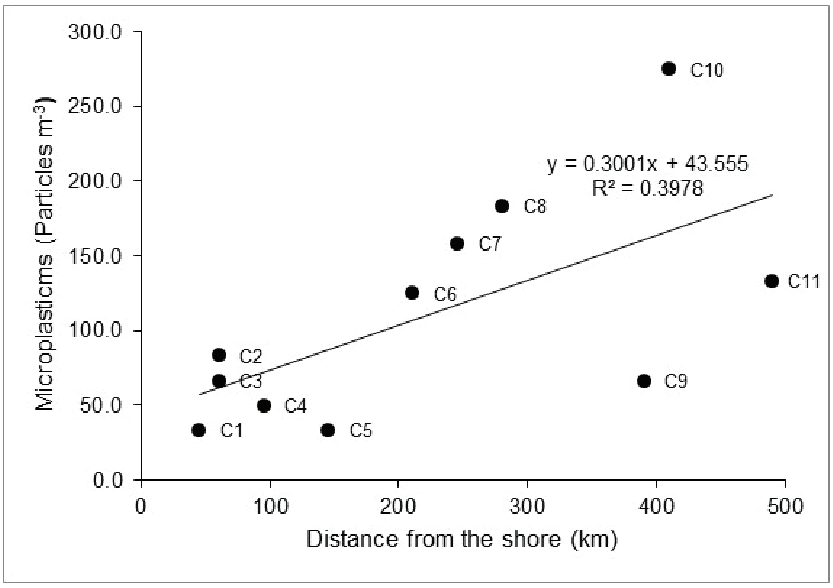

Figure 5.9.2:The association between microplastics abundance and distance from the shore (Kosore et. al. 2018)

reported in Qatar EEZ (Castillo *et al.* 2016).

Most of the ingested microplatics were flexible filaments of various sizes and colours (Plate 5.9.1) A total of 129 microplastics particles were found ingested by the zooplankton groups, with the majority of the particles being ingested at C8 (24 particles), followed by C2 (20 particles) and C3 (19 particles). No microplastics were found ingested at station C1.

A total of 129 particles were found ingested by the zooplankton groups, which comprised only filaments and fragments. The rate of ingestion of microplatics was highest for Chaetognatha and the lowest rate of ingestion was for fish larvae (Table 5.9.2). Filaments were the dominant particle shape recorded with 1.1 particles ind.$^{-1}$ (n = 125, 97%), with fragments at 0.04 particles ind.$^{-1}$ (n = 4, 3%). Thirty six of the 129 ingested particles were measured and categorised as 0.01–0.1mm (n = 16), 0.1–0.4mm (n = 16) and 0.5–1.6mm (n = 4). For the filaments and fragments, black was the colour found most commonly (n = 53, 42%), followed by red and brown (each 17%, n = 21), blue (13%, n = 19), green (9%, n = 13) and orange (2%, n = 2).

The differences observed in the number of particles ingested per individual zooplankton group is a result of different feeding habits. Copepods mainly feed on phytoplankton, protists and marine snow/aggregates, whereas Chaetognatha and fish larvae feed on zooplankton (Sun *et al.* 2016). Furthermore, copepods might also be more susceptible to ingesting polypropylene, polyethylene or polystyrene, which have densities below that of seawater (~1.02 g cm^{-3}), because they feed near the surface (Clark *et al*. 2016). The prevalence of ingestion of filaments by the zooplankton groups might not only reflect their apparent predominance in the environment but also might have been enhanced by the fact that filaments are capable of self-folding and twisting, which reduce their overall size and thus potentially increase their bioavailability (Desforges *et al*. 2015). Microplastic particles of various colours were ingested by the zooplankton groups, with black being the colour found most commonly in all groups combined.

ATR-FTIR analysis showed that PP and LDPE were the only polymers identified among particles from the water samples, where PP was the most common followed by LDPE. For the ingested microplastics, only LDPE was identified. PP was identified at all sampling stations. Its resistance to high temperatures of 55–70 °C (Qiu *et al*. 2016), wide application and relatively low cost lead to its prolific use in a wide range of consumer products, and it is thus often the predominant polymer found in the environment (Castillo *et al*. 2016). Density might also be a factor that influences the presence of PP and LDPE, in that both PP (0.89–0.91 g cm^{-3}) and LDPE (0.093–0.98 g cm^{-3}), are lighter than seawater and are expected to be positively buoyant in seawater and to be retained on the sea surface, becoming concentrated in areas of low circulation (Castillo *et al*. 2016). This makes them more available to ingestion by zooplankton.

5.9.4. Conclusion

The results of this study confirm the presence of microplastics in Kenya's marine environment and their ingestion by zooplankton, thus entering pelagic food web. In addition, the microplastics abundance is related to environmental factors. Filaments and white particles are predominant in the water, whereas black particles had the highest occurrence of the ingested microplastics. The dominant polymer in the water was PP, whereas LDPE was the only ingested polymer identified.

The study provided information on microplastics abundances and composition that zooplankton might be exposed to, and hence provided baseline data from which monitoring of microplastics in Kenya's marine environment might develop. The results obtained provide the basis for expansion of this study to inshore areas, which could lead to the identification of the sources of microplastics and the development of mitigation measures to reduce or eliminate microplastic pollution.

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Annexes

Annex I. Training and research cruises undertaken on board RV Mtafiti from 2015 to 2018

No	Data set
1	Bathymetry Elevation (m) of the Kenyan and the Exclusive Economic Zone _Block2_RVMtafiti_Cruise4_Data
2	Bathymetry Elevation (m) of the Kenyan and the Exclusive Economic Zone - Block3_RVMtafiti_Cruise5_Data
3	Bathymetry Elevation (m) of the Kenyan and the Exclusive Economic Zone EK60_Training_RVMtafiti_Training2_Data
4	Bathymetry Elevation (m) of the Kenyan and the Exclusive Economic Zone _Block1_RVMtafiti_Cruise3b_Data
5	Bathymetry Elevation (m) of the Kenyan Territorial_RVMtafiti_Cruise3a_Data
6	Fish_acoustics_20161217_Mombasa_Training1_Data_AKimeli
7	RV. Mtafiti cruise phytoplankton - December 2015
8	Phytoplankton distribution and abundance data collected on RV Mtafiti Cruise 1
9	Fish Hydro acoustics EEZ_NEM_block2_38KHz_RVMtafiti_Bathypelagics_Day_ Cruise4
10	Fish Hydro acoustics EEZ_NEM_block2_38KHz_RVMtafiti_Bathypelagics_Night_ Cruise4
11	Fish Hydro acoustics NEM_block2_38KHz_RVMtafiti_Mesopelagics_Day_Cruise4
12	Fish Hydro acoustics NEM_block2_38KHz_RVMtafiti_Pelagics_Day_Cruise4
13	Fish Hydro acoustics NEM_block2_38KHz_RVMtafiti_Pelagics_Night_Cruise4
14	Fish Hydro acoustics Block3_NEM_RVMtafiti_38kHz_BathyPelagic_Night_Cruise5
15	Fish Hydro acoustics Block3_NEM_RVMtafiti_38kHz_MesoPelagic_Night_Cruise5
16	Fish Hydro acoustics NEM_Block3_RVMtafiti_38kHz_BathyPelagic_Day_Cruise5
17	Fish Hydro acoustics NEM_Block3_RVMtafiti_38kHz_MesoPelagic_Day_Cruise5
18	Fish Hydro acoustics NEM_Block3_RVMtafiti_38kHz_Pelagic_Day_Cruise5
19	Fish Hydro acoustics NEM_Block3_RVMtafiti_38kHz_Pelagic_Night_Cruise5
20	20161219_territorial_RVMtafiti_Metadata_Cruise6 – nutrients
21	RV Mtafiti Block 2 Cruise 2 Research of 2017 North East Monsoon – hydographic parameters
22	WC_Nuts_20161219_Block1_RVMtafiti_Metadata_Cruise6_JKamau_ hydographic parameters

Annex II. Standard Operating Procedures adopted for use in RV Mtafiti

Chemical Oceanography

- Standard Operating Procedures for Measurement of pH, Temperature, Do, Salinity and Conductivity Using Multi-Parameters Meters
- Standard Operating Procedures for Total Suspended Solids Determination Using Vacuum Filtration and Oven Drying
- Standard Operating Procedures for Filtered Chlorophyl a Determination Using Vacuum Filtration and Uv-Vis Spectrometry
- Standard Operating Procedure for the Analysis of Particulate Organic Matter (POC) in Sea Water
- Standard Operating Procedure for the Analysis of Iron in Sea Water
    a. Use Clean Hands/Dirty Hands (CH/DH).
    b. ICP-OES Procedures
- Standard Operating Procedure for the Analysis of Nitrate/Nitrite and Nitrite; Phosphate; Ammonia and Silicate in Sea Water
    a. Water Samplers
    b. Standard Operating Procedure for the Determination of Nitrate/Nitrite and Nitrite in Seawater (Sop N/1)
    c. Standard Operating Procedure for the Determination of Ammonia in Seawater (Sop Nh4/1)
    d. Standard Operating Procedure for the Determination of Phosphate in Seawater (Sop Po4/1)
    e. Standard Operating Procedure for the Determination of Silicate in Seawater (Sop Si/1)
    f. Preparation Of Primary Standards

Biological Oceanography

- Standard Operating Procedures for Benthic Sampling
- Standard Operating Procedures for Phytoplankton Sampling
- Standard Operating Procedures for Zooplankton Sampling
- Marine Mammals, Seabirds and Marine Turtles Survey Protocol

Microplastics

- Standard Operating Procedures for Marine Neustonic Microplastics
- Standard Operating Procedures for the Determination of Microplastics in Marine Neustonic Zooplankton
- Standard Operating Procedure for Grainsize Analysis

Geological Oceanography

- Standard Operating Procedure for Surface & Sub-Bottom Sediment Sampling
- Standard Operationg Procedures for Organic Matter In Marine Sediments Using Loss on Ignition (Loi) Method

Physical Oceanography

- Standard Operating Procedure Rv Mtafiti ADCP
- Standard Operating Procedure for Hydroacoustic Survey

Annex III. List of data sets collected aboard RV Mtafiti and subsequently documented

Taxa	Kilifi - Malindi	Mombasa	Kwale
Alexandrium spp.	7.88	40.28	5
Amphidinium spp.	2.5	12.5	7.5
Anabaena spp.	2.5	16.67	7.5
Chrysochromulina		15.63	
Chrysochromulina spp.	4.17	12.5	
Dinophysis caudata			2.5
Dinophysis fortii		25	5
Dinophysis rotundata		25	
Dinophysis spp.	2.5	17.86	
Gambierdiscus spp.	2.5	13.28	2.5
Gonyaulax polygramma			1.67
Gonyaulax spp.	3.75	27.65	15.42
Gymnodinium spp.	4.69	21.3	
Gyrodinium spp.		16.67	
Lingulodinium polyedrum		12.5	1.67
Lingulodinium spp.	5		1.67
Nitzschia closterium		106.25	3.33
Nitzschia reversa			2.5
Nitzschia sigma			1.67
Nitzschia spp.	4.17	20.14	2.92
Nodularia spp.		14.58	
Ostreopsis spp.	12.5	46.12	
Phalacroma mitra	5		
Phalacroma rotundatum	2.5	20.31	
Phalacroma spp.	2.5		1.79
Prorocentrum concavum			1.67
Prorocentrum micans		12.5	10
Prorocentrum spp.	5	19.2	8.54
Protoceratium spp.			5
Pseudo-nitzschia spp.	8.75	**1444.26**	4.72
Pseudo-nitzschia subpacifica		50	
Pyrodinium spp.	2.5		

Annex IV. Mean cell densities (Cells L-1) of HAB species in surveyed areas within Kenya's territorial waters

Taxa	Kwale	Kilifi	Malindi	Lamu
Alexandrium spp.		5	5	11.25
Amphidinium spp.			5	
Anabaena spp.				40
Cylindrospermopsis spp.			20	
Dinophysis spp.	2.5	5	3.75	3.13
Gambierdiscus spp.	2.5	1		3.75
Gonyaulax spinifera				10
Gonyaulax spp.	7.50	8.75	5	6.25
Gymnodinium spp.				5
Lingulodinium spp.	2.5			
Nitzschia closterium			2.5	
Nitzschia reversa				5
Nitzschia spp.		7.5		2.5
Ostreopsis spp.		12.5	10	5
Phalacroma rotundatum				2.5
Phalacroma spp.		7.5	2.5	
Prorocentrum micans				4.17
Prorocentrum spp.	2.5	5	2.5	4.38
Protoceratium spp.	12.5		5	
Pseudo-nitzschia spp.	2.5	8	3.75	10.42

Annex V. Mean cell densities (Cells l^{-1}) of HAB species in surveyed areas within Kenya's EEZ waters

Taxa	Kilifi - Malindi	Mombasa	Kwale
Alexandrium spp.	7.88	40.28	5
Amphidinium spp.	2.5	12.5	7.5
Anabaena spp.	2.5	16.67	7.5
Chrysochromulina pringheimii		15.63	
Chrysochromulina spp.	4.17	12.5	
Dinophysis caudata			2.5
Dinophysis fortii		25	5
Dinophysis rotundata		25	
Dinophysis spp.	2.5	17.86	
Gambierdiscus spp.	2.5	13.28	2.5
Gonyaulax polygramma			1.67
Gonyaulax spp.	3.75	27.65	15.42
Gymnodinium spp.	4.69	21.3	
Gyrodinium spp.		16.67	
Lingulodinium polyedrum		12.5	1.67
Lingulodinium spp.	5		1.67
Nitzschia closterium		106.25	3.33
Nitzschia reversa			2.5
Nitzschia sigma			1.67
Nitzschia spp.	4.17	20.14	2.92
Nodularia spp.		14.58	
Ostreopsis spp.	12.5	46.12	
Phalacroma mitra	5		
Phalacroma rotundatum	2.5	20.31	
Phalacroma spp.	2.5		1.79
Prorocentrum concavum			1.67
Prorocentrum micans		12.5	10
Prorocentrum spp.	5	19.2	8.54
Protoceratium spp.			5
Pseudo-nitzschia spp.	8.75	1444.26	4.72
Pseudo-nitzschia subpacifica		50	
Pyrodinium spp.	2.5		

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